CHAPTER 2

GAS TURBINE MAINTENANCE

This chapter will cover object damage, borescope inspection, troubleshooting, and maintenance of the LM2500 and the Allison 501-K series of GTEs. The majority of this chapter deals with the LM2500 GTE damage evaluation. The last part of this chapter is on proper preservation and corrosion control methods for maintaining all GTEs in peak operating status.

OBJECT DAMAGE

There are two basic types of object damage GS supervisors see. One of the most damaging gas turbine casualties, and one of the easiest to prevent, is foreign object damage (FOD). In this section we will discuss the hazards of FOD and some of the ways to prevent it. The other type of object damage that can cause failure of a GTE is domestic object damage (DOD).

HAZARDS

The effects of object damage and the hazards involved vary greatly with the size and location of the object ingested. Small dents and abrasions may cause little or no damage. However, if a large enough object is ingested by the engine, severe internal damage will result. Large, soft items (such as paper) can clog the FOD screen, causing a loss of power and elevated turbine inlet temperatures. The other type of damage that was mentioned is DOD. DOD occurs when an internal object from the engine breaks loose and causes impact damage to the engine.

PREVENTION

To prevent FOD to engines while working in and around intake and plenum areas, you and your personnel must observe the following safety precautions:

—When performing maintenance inside the intake areas, always-follow all written guidelines found in the EOP. Remember to remove all loose objects from your person. You must also account for all tools and equipment used in the intake. After completing your work, inspect the intake for cleanliness, and reinventory the tools and equipment before securing the accesses.

—Periodically inspect all intakes for cleanliness, the state of preservation, and the condition of the FOD screens. Correct any abnormal conditions. The frequency of inspection will depend on the operating conditions, PMS requirements, and engineering department instructions. Remember, the PMS only provides minimum standards. PMS can always be exceeded if you or your superiors deem it necessary.

—When inspecting the intakes, be sure that the areas around the blow-in doors are kept clear of loose gear and debris that could be ingested if the blow-in doors are activated.

To prevent DOD damage, you and your personnel need to follow a strict regiment of cleaning and inspections (internal and external). This attention to detail, as described in the next two paragraphs, is absolutely necessary to avoid DOD damage.

—Make sure the engine is properly cleaned inside and out. Always following the standards in the PMS and the manufacturer's technical manual. Cleanliness is an important factor in the fight against corrosion. Corrosion control (discussed later in this chapter) also can reduce the chances of component failures that can lead to DOD.

—Perform frequent external and internal GTE inspections to reduce the possibilities of DOD occurrences. GTE external inspections are very important. Locating loose, missing, or broken external components (VSV retaining nuts) during these inspections is a significant factor in preventing damage.

—Using borescope inspections aids in determining the extent and prevention of DOD. The most frequent damage is identified as potential component failures (blade stress cracks).

BORESCOPE INSPECTIONS

Borescope inspection requirements and procedures are found on the maintenance requirement card (MRC). These cards contain all the basic information necessary to conduct an inspection. Included on the MRCs are the serviceability limits and a list of conditions that require an inspection. Borescope inspections are usually performed semiannually or when the engine has been operated beyond the allowable limits listed on the MRC.

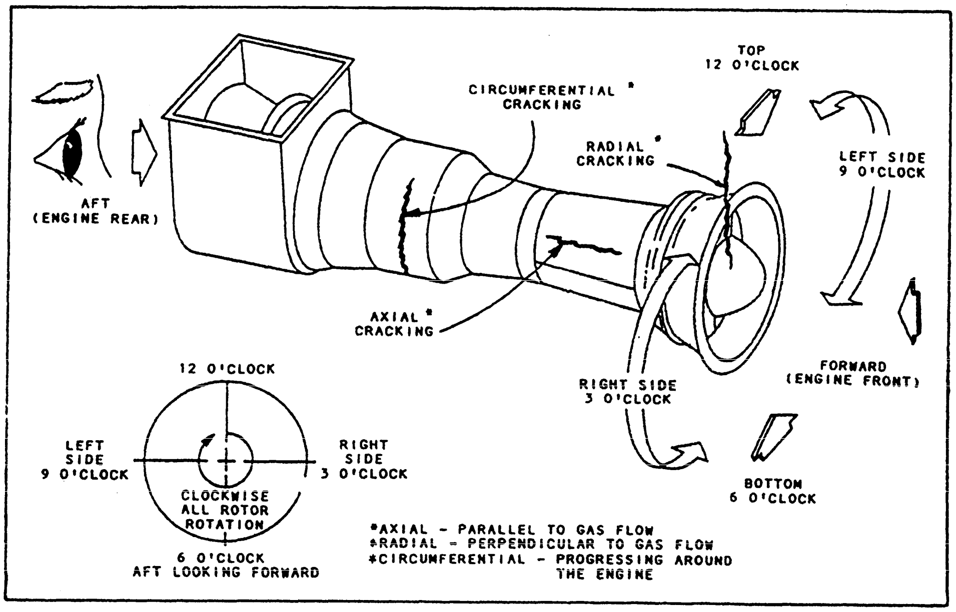


Figure 2-1.—Geometric orientation of the LM2500 GTE

The following section discusses the borescope procedures used to inspect the LM2500 GTE. The inspection procedures and the knowledge gained from damage evaluation may also be applied to the borescope inspection of the Allison 501-K17 GTE.

GENERAL INSPECTION PROCEDURES

It is a good engineering practice to review the machinery history of an engine before you conduct an inspection Various component improvement programs will eventuallyy effect all engines in service. A rebuilt or modified engine may contain improved parts that differ from the original. An example of this is the first-stage compressor midspan damper that may have its original coating, an improved coating, or a carboloy shoe welded on at the midspan damper interface. If you review the machinery history, you will discover the status of those parts that have been changed or modified.

Assuming that the engine history is normal and FOD is not suspected, you should be aware of the following factors when conducting a borescope inspection:

- Know your equipment.
- Locate all inspection areas and ports.

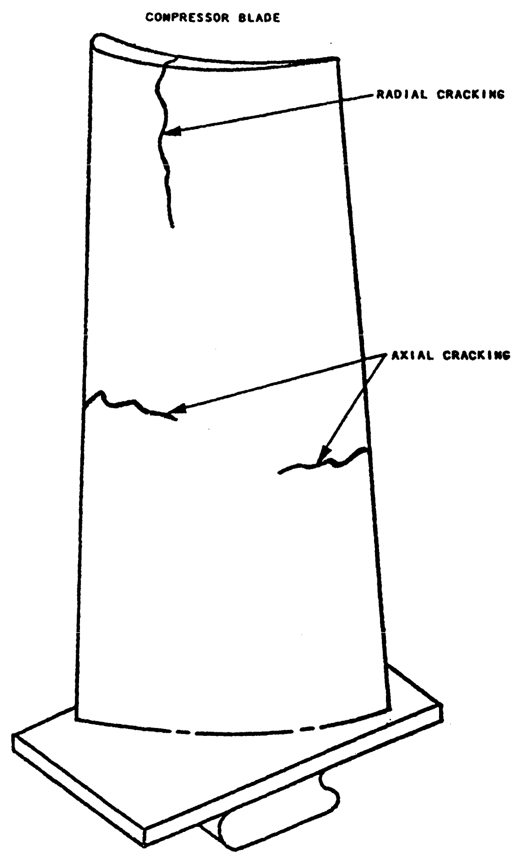


Figure 2-2.—Example of radial and axial cracking.

- Establish internal reference points.
- Scan the inspection area thoroughly and in an orderly manner.
- Note any inconsistencies.
- Evaluate the inconsistencies.
- Report your conclusions.

GEOMETRIC ORIENTATION OF THE ENGINE

To communicate information about an engine inspection, you must establish a geometric frame of reference for the engine assembly. A language for describing the physical damage is also necessary. An example of this information is provided in figure 2-1, geometric orientation of the LM2500 GTE. Figure 2-2 shows an example of radial and axial cracking on a compressor blade; figure 2-3 shows an example of circumferential and axial cracking in the combustion section. Table 2-1, a foldout at the end of this chapter, provides a list of condition codes and definitions of terms that you need to know when inspecting the LM2500 GTE.

When the probe is in the inspection hole, it is not unusual for you to lose your sense of direction. On the Wolf borescope, the large plastic disk just beneath the eyepiece has an index mark that shows the direction the probe object window is facing. You can feel and see this mark. Another reference you can use to detect the direction the object window is facing is

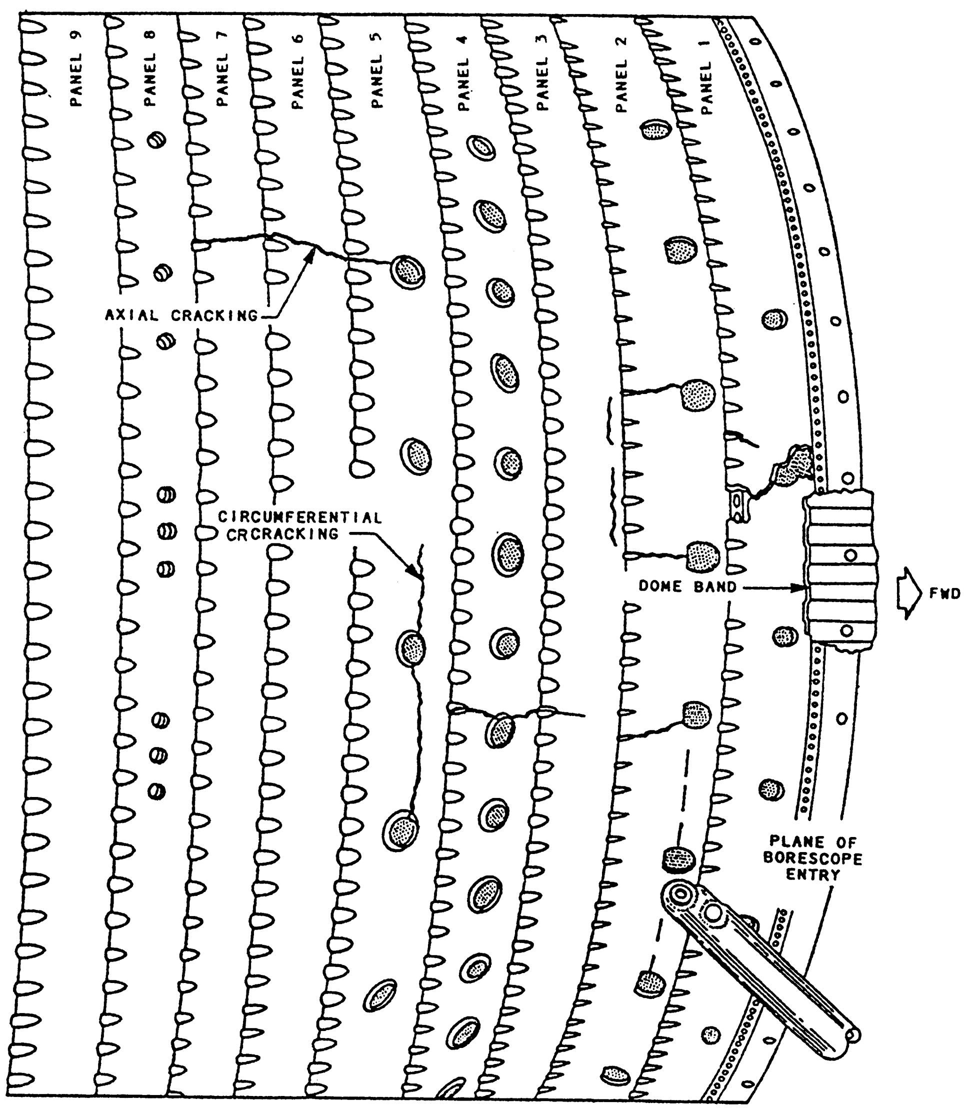


Figure 2-3.—Examp1es of circumferential and axial cracking.

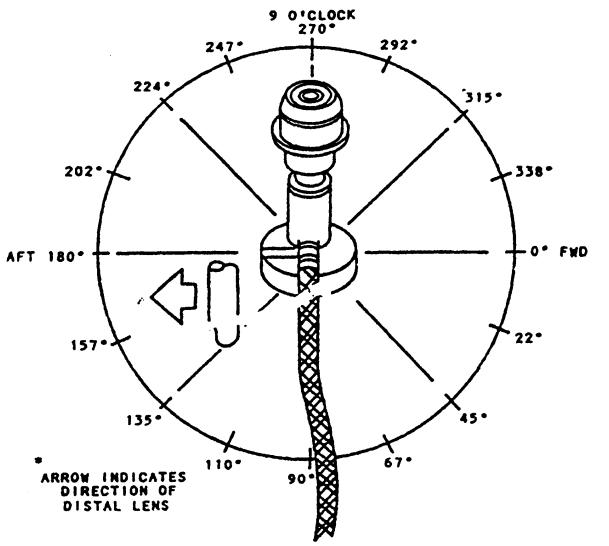


Figure 2-4.—Light cable azimuth for borescope probes.

the light cable attachment. On the Wolf and Eder probes, the viewing window is 90 degrees clockwise from the light cable, as shown in figure 2-4. In the future, borescoping equipment may have changes incorporated that significantly improve the inspection equipment. Newer models may incorporate a swiveling light cable that allows the cable to hang down regardless of the viewing direction. You must read the manufacturer's instruction manual before you can successfully use the equipment. Figure 2-5 is an example of how the engine and borescope geometry work together. It shows you how the borescope appears when looking forward and aft from the right side of the engine or from the left side of the engine.

BORESCOPE PORTS

Table 2-2 is a description of the ports and the areas that you can see from each borescope port. Figure 2-6 shows you the component materials and the temperatures at which the various components normally operate. The locations

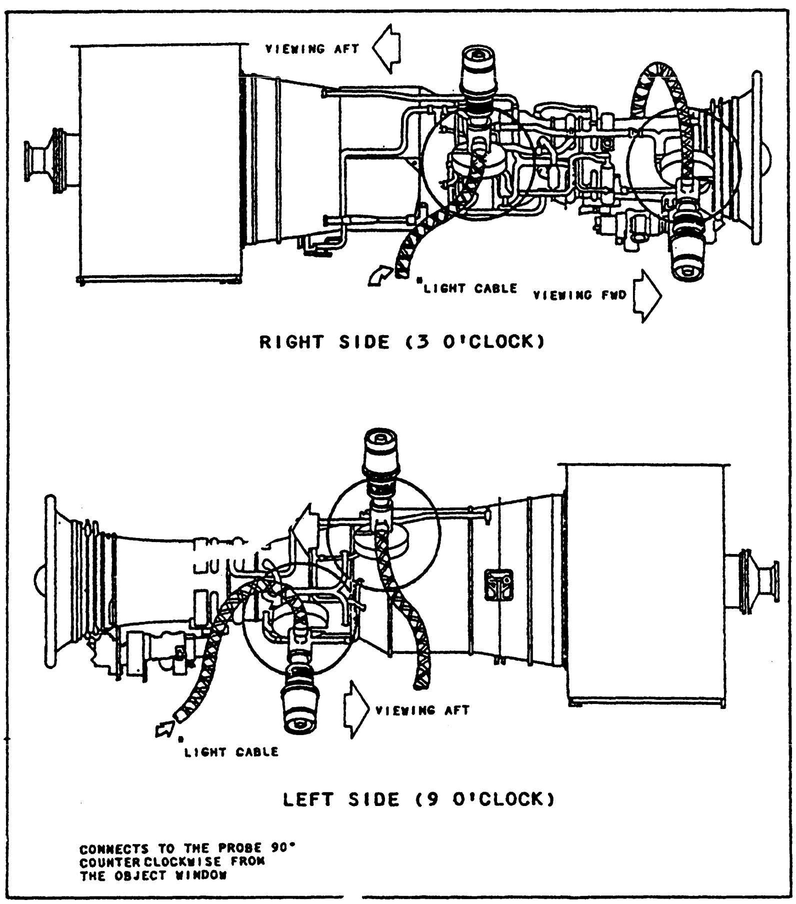


Figure 2-5.—Geometric orientation of the borescope.

Table 2-2.—Area Visible From Borescope Inspection Ports

PORT IDENTIFICATION	PART/AREA ACCESSIBLE FOR INSPECTION
29	Two Inlet Guide Vane Airfoils
28	Stages 1 and 2 Compressor Rotor Blades and two Stage 1 Stator Vane Airfoils
27	Stages 2 and 3 Compressor Rotor Blades and two Stage 2 Stator Vane Airfoils
26	Stages 3 and 4 Compressor Rotor Blades and two Stage 3 Stator Vane Airfoils
25	Stages 4 and 5 Compressor Rotor Blades and two Stage 4 Stator Vane Airfoils
24	Stages 5 and 6 Compressor Rotor Blades and two Stage 5 Stator Vane Airfoils
23	Stages 6 and 7 Compressor Rotor Blades and two Stage 6 Stator Vane Airfoils
22	Stages 7 and 8 Compressor Rotor Blades and two Stage 7 Stator Vane Airfoils
21	(Blocked)
20	Stages 9 and 10 Compressor Rotor Blades and two Stage 9 Stator Vane Airfoils
19	Stages 10 and 11 Compressor Rotor Blades and two Stage 10 Stator Vane Airfoils
18	Stages 11 and 12 Compressor Rotor Blades and two Stage 11 Stator Vane Airfoils
17	Stages 12 and 13 Compressor Rotor Blades and two Stage 12 Stator Vane Airfoils
16	Stages 13 and 14 Compressor Rotor Blades and two Stage 13 Stator Vane Airfoils
15	Stages 14 and 15 Compressor Rotor Blades and two Stage 14 Stator Vane Airfoils
14	Stages 15 and 16 Compressor Rotor Blades and two Stage 15 Stator Vane Airfoils
13	Combustor, Fuel Nozzles, and Stage 1 HP Turbine Nozzle
12	Stage 1 HP Turbine Rotor Blades and two Stage 1 HP Turbine Nozzle Airfoils
11	Stages 1 and 2 HP Turbine Rotor Blades and two Stage 2 HP Turbine Nozzle Airfoils
10	Stage 2 HP Turbine Rotor Blades, Stage 1 LP Turbine Blades and Vanes, Turbine Mid-Frame Liner, and $T_{5.4}$ Thermocouple Probes

of the borescope inspection ports are shown in figure 2-7.

Compressor

Fifteen borescope inspection ports are in the compressor near the 3 o'clock split line. A port is located at every compressor stator stage. These vane ports start at the IGVs and work aft in the same direction as the airflow (except for stage 8, which is internally blocked). Stator stages 9 and 13 borescope ports require you to remove piping interferences.

Combustor and HP Turbine

Aft of the right-hand side compressor ports are six circumferentially positioned ports, just forward of the midflange of the compressor rear frame. From these ports you can inspect the combustor, the stage 1 HP turbine nozzle assembly, and a few fuel nozzles. Near the aft flange of the compressor rear frame on the right-hand side of the engine are two HP turbine stator ports that you can use for viewing the air-cooled turbine blades. The $P_{t5.4}$ pressure probe harness adjacent to the after flange of the turbine midframe is located aft of the

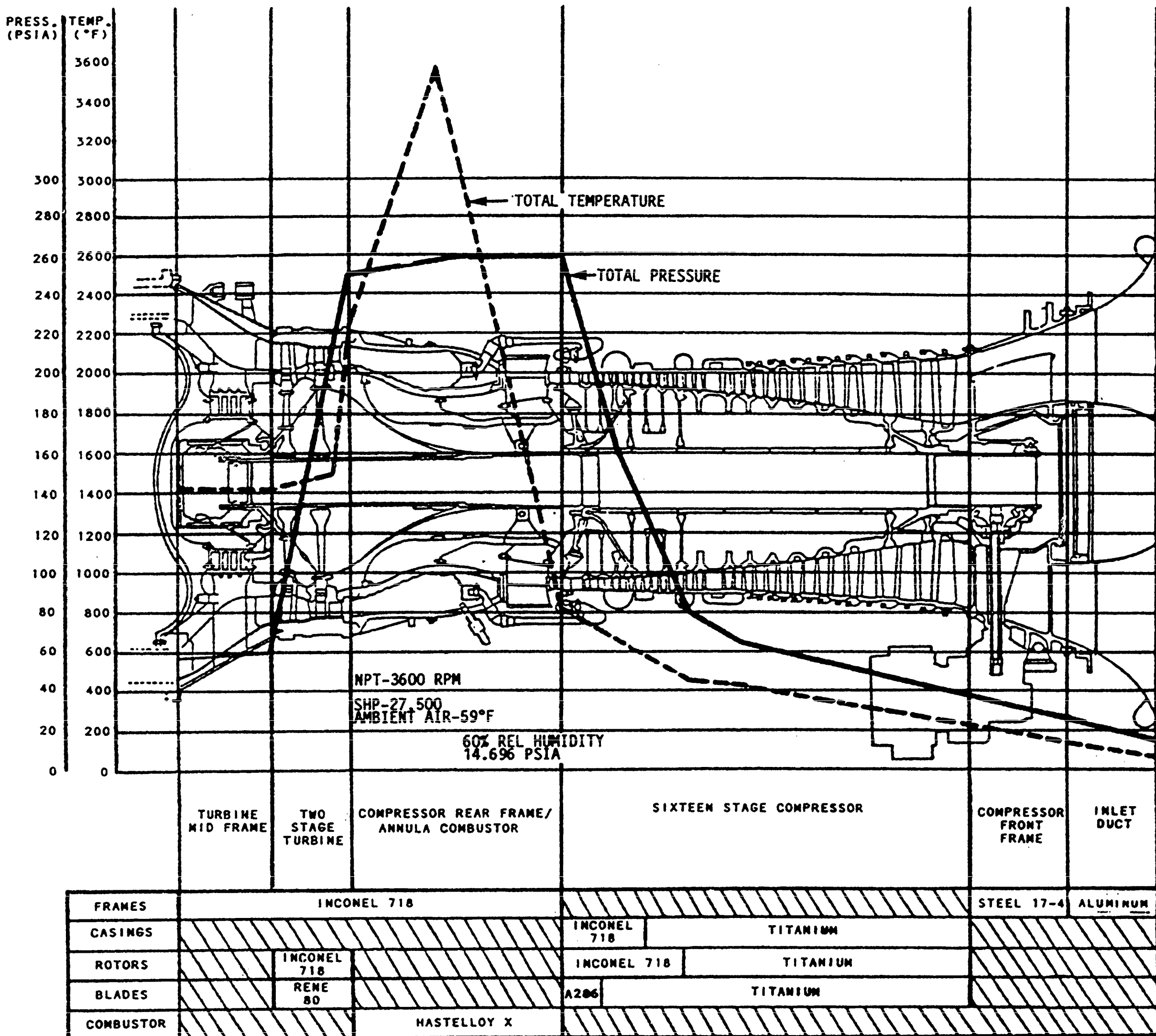
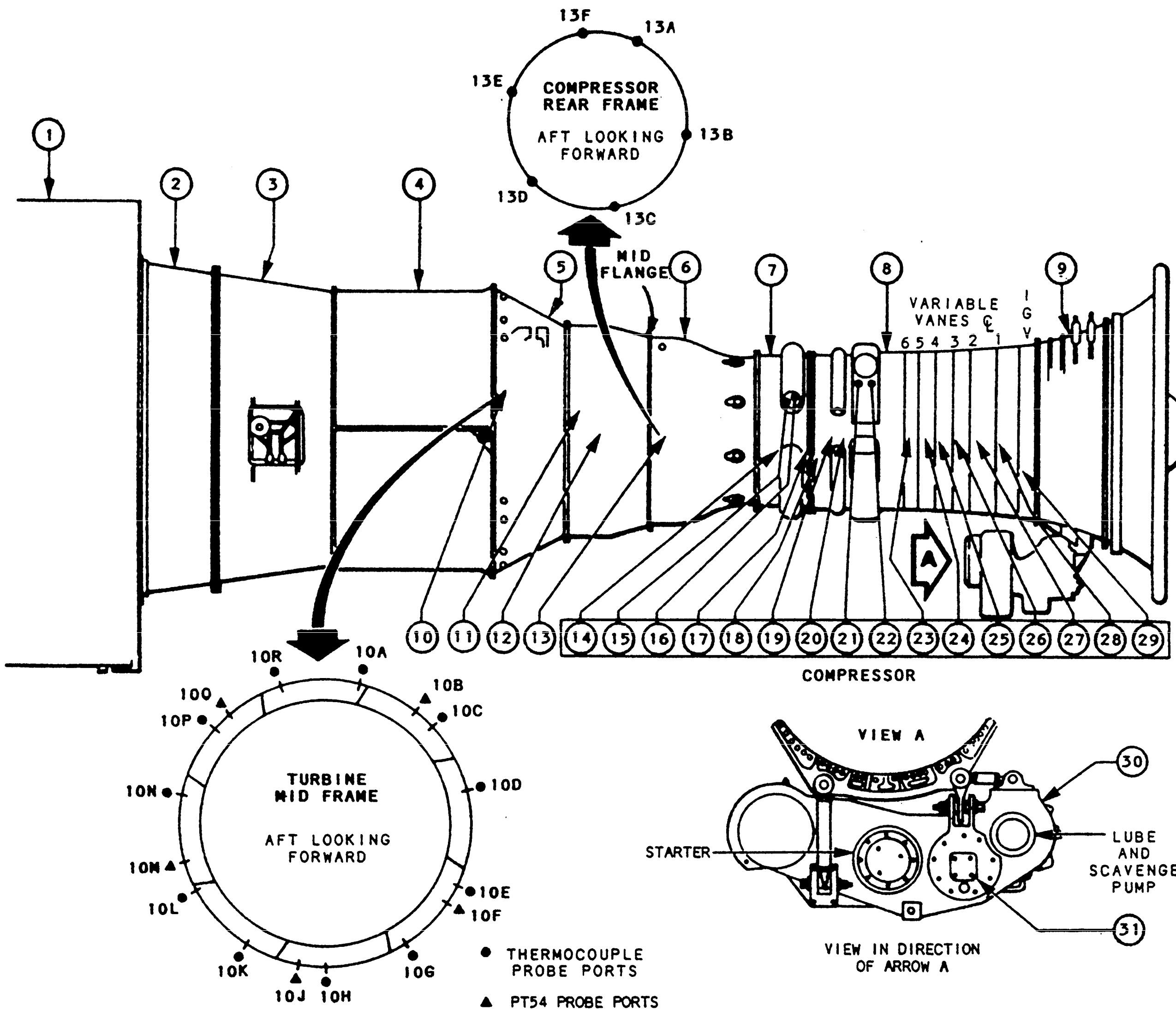


Figure 2-6.—Turbine materials and operating conditions.

stage land 2 turbine ports. Five pressure probes are located circumferentially around the turbine midframe at the inlet to the LP turbine. All five probes extend radially into the gas path and can be removed to inspect the LP turbine inlet and the HP turbine exhaust.

INDEXING AND ROTATING THE ENGINE

You can rotate the engine by using a socket wrench with an 18-inch long 3/4-inch drive extension. You attach the 3/4-inch drive extension after you remove the cover plate on the aft face, right-hand side of the accessory gearbox, next to the lube and scavenge pump (fig. 2-8). When you are inspecting through the forward-most borescope ports, there is not enough space for both you and the person turning the engine to work This requires you to do the turning yourself or to have the turner rotate the engine from the other location on the accessory gearbox. You can find the alternate drive pad for manual engine turning on the forward face, left-hand side of the accessory gearbox, also shown in figure 2-8.



1. Exhaust Duct	11. Compressor Rear Frame Port	21. Stage 8 port
2. Outer Cone	12. Compressor Rear Frame Port	22. Stage 7 port
3. Turbine Rear Frame	13. Compressor Rear Frame Port	23. Stage 6 port
4. Turbine Case	14. Stage 15 port	24. Stage 5 port
5. Turbine Mid Frame	15. Stage 14 port	25. Stage 4 port
6. Compressor Rear Frame	16. Stage 13 port	26. Stage 3 port
7. Rear Compressor Casing	17. Stage 12 port	27. Stage 2 port
8. Front Compressor Casing	18. Stage 11 port	28. Stage 1 port
9. Compressor Front Frame	19. Stage 10 port	29. Stage 0 port
10. Turbine Mid Frame Ports	20. Stage 9 port	30. Transfer Gearbox
		31. Drive Pad Cover Plate

Figure 2-7.—Borescope inspection ports.

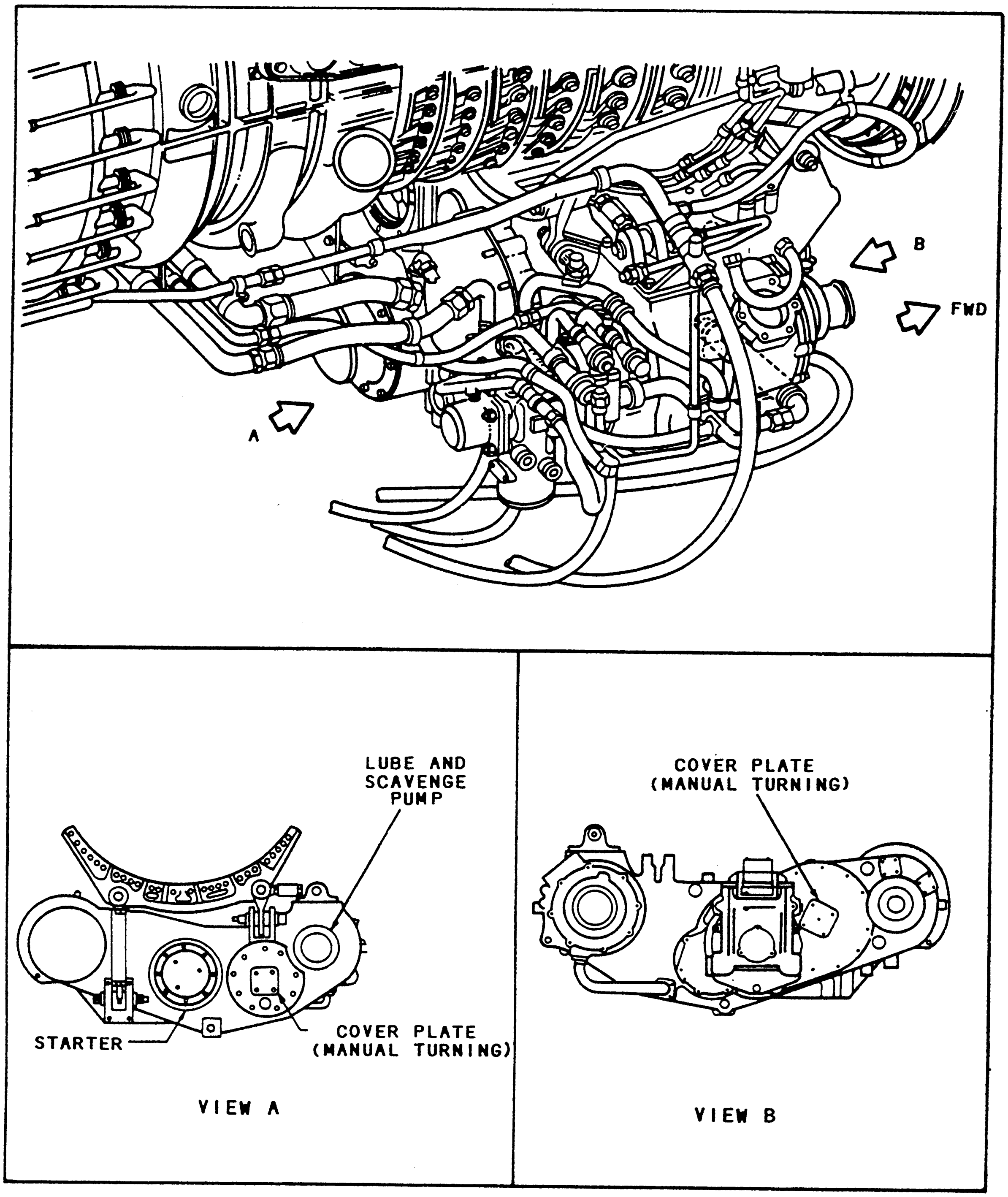


Figure 2-8.—Engine turning locations for borescope inspections.

Detailed procedures are provided for indexing and rotating the engine on the MRC. Figures 2-9 and 2-10 show the accessory drive gear ratios and the locking lugs used for indexing the compressor rotor. Zero reference for the compressor and HP turbine stages is established by use of the locking lug blades. Establishing the zero reference ensures a complete inspection for each stage. It also provides you an immediate circumferential reference point for distress reporting for each stage. You should not concentrate on counting the blades. Instead, concentrate on the specific condition of each airfoil as it passes. The forward and aft drive pads have different drive ratios to the main rotor shaft. You may find it advantageous to use a torque multiplier to slow down and maintain better control over the main rotor speed. Depending on the manual drive setup, you will be able

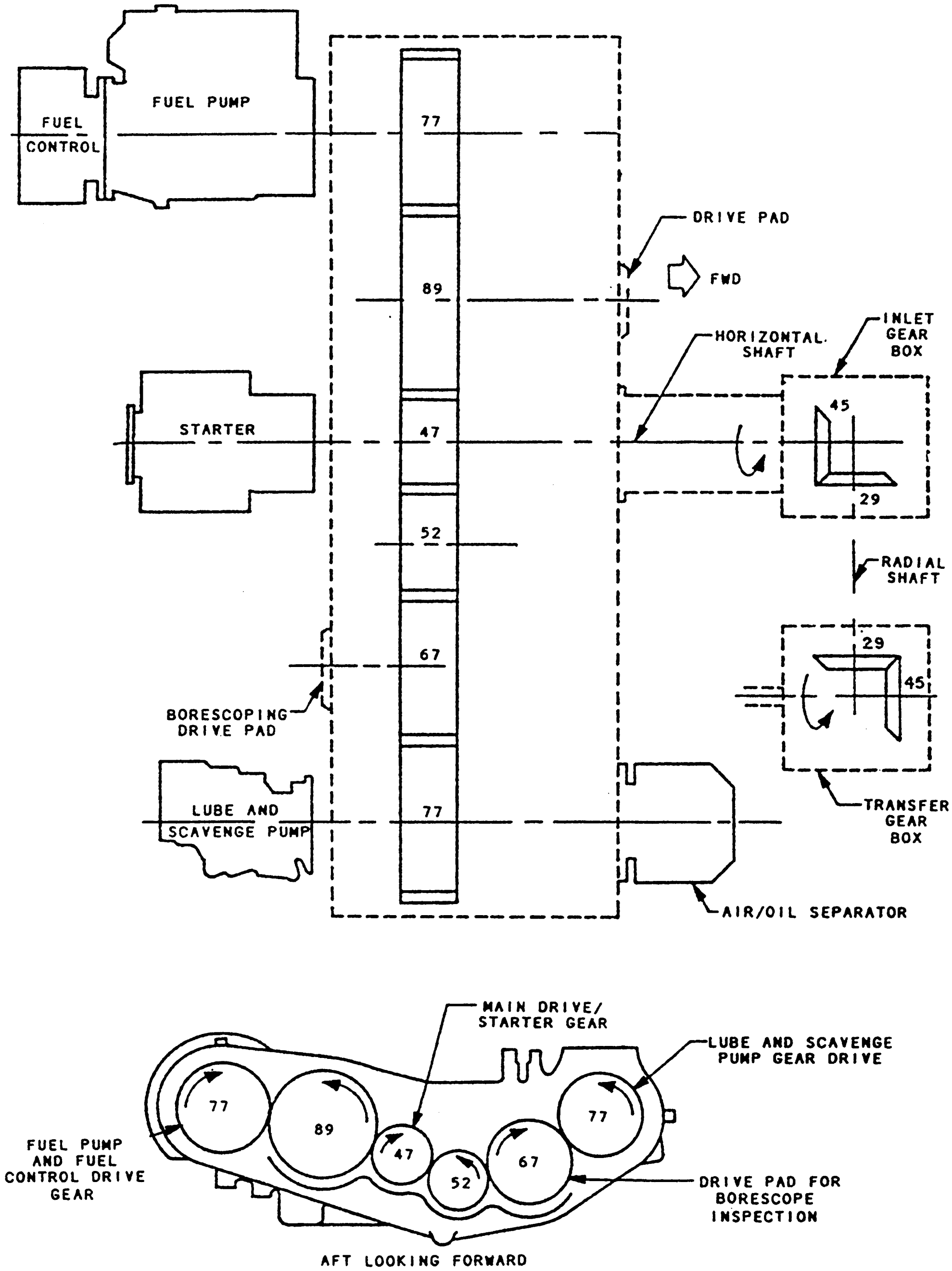


Figure 2-9.—Accessory drive gear ratios.

to establish how many full arcs of the ratchet wrench are required to move the main rotor one full revolution. For example, when you are using the forward pad, a 344-degree revolution of the input drive equals 360 degrees on the main rotor.

SERVICE LIMITS

This section discusses the types of damage that you might find when conducting a routine inspection. This material will be limited to a discussion of the major engine areas. The parts nomenclature that is used in this section is found in figure 2-11, a foldout at the end of this chapter.

Compressor Section

You should inspect the compressor section for nicks and dents, cracks, spacer rubs, casing rubs, blade tip rubs, bent edges, missing pieces, and trailing edge erosion. Inspect the first-stage compressor midspan damper for leading edge dents and other types of

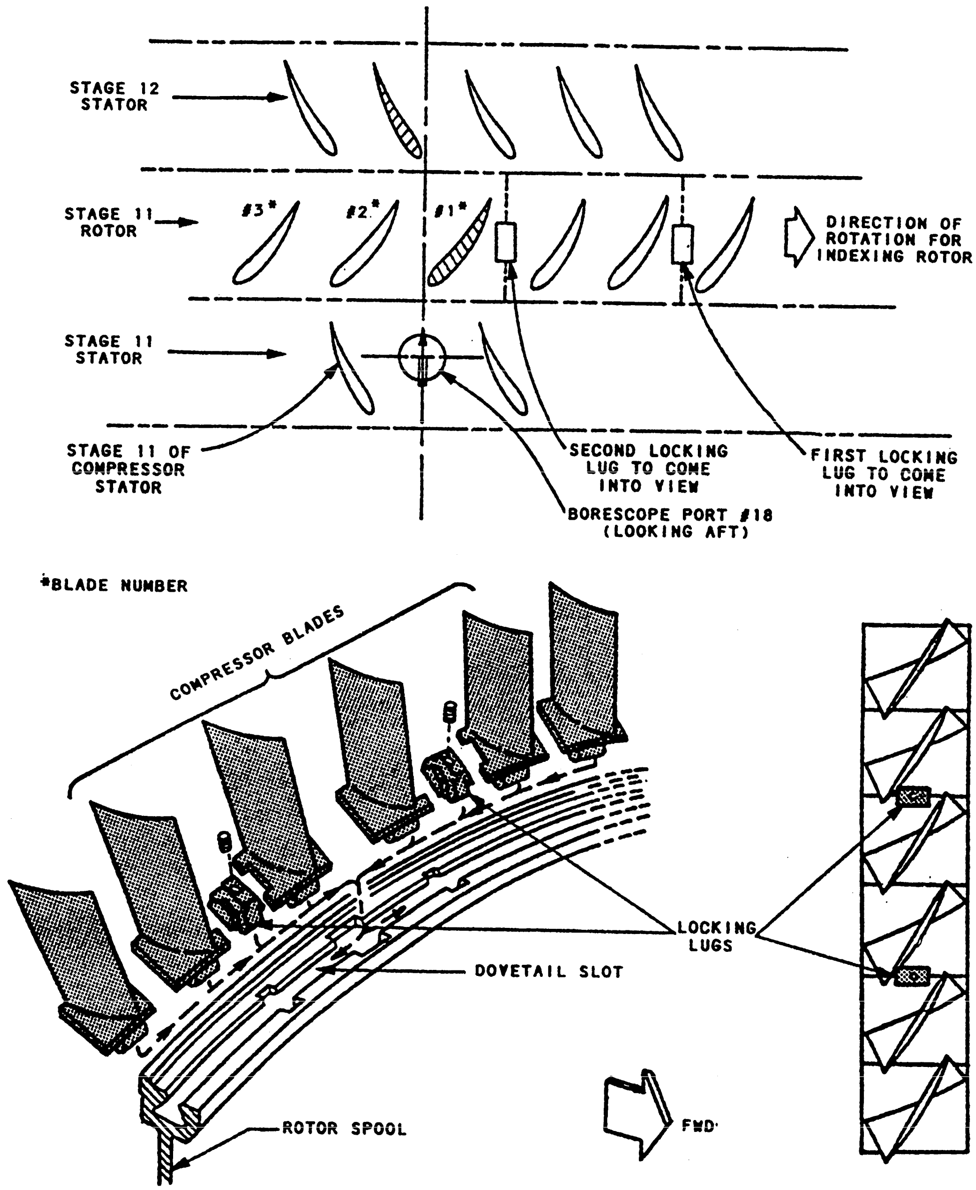


Figure 2-10.—Zero indexing the compressor rotor.

damage. Beginning with the third stage, if a slight tilting of the blade or raising of the blade platform is observed, suspect blade root failure. This condition requires suspended engine operation until the condition has been evaluated

COMPRESSOR DAMAGE.— In tie following paragraphs, redescribe some of the damage you may find during an engine inspection. You can find the condition codes used to describe engine damage in foldout table 2-1.

Airfoil and Tip Cracks.— Cracks in the compressor hardware are difficult to detect because they are tight and shallow in depth. You can miss these subtle defects because of deteriorated borescope optics or if you rotate the rotor too fast. You should record all crack information relative to the stage, area, magnitude, direction, and adjacent blade condition.

Cracked Dovetail.— A cracked dovetail of a blade may lead to blade loss. The location of the blade will determine the extent of engine damage. Before the actual catastrophic failure of the blade, the separated crack in the dovetail will be evident by a leaning blade platform. You can find this fault by using the borescope to inspect each blade platform. The leaning blade platform will be higher than the adjacent nonleaning blades. A "leaner" is a blade that has a crack on the aft side of the dovetail and is leaning in the forward direction (fig. 2-12). If a leaner is detected, it must be verified and the engine should be removed from service.

Airfoil and Tip Tears.—The most critical area of a torn blade is the area around the end of the tear and its location on the airfoil. You should inspect this area for cracks that lead from the tear and are susceptible to propagation. This condition could lead to the loss of the airfoil section that would create downstream impact damage. You should record all information such as stage, blade locations, area of the blade in which the defect was found, and the condition of the rest of the airfoil and adjacent airfoils. Section A of figure 2-11 shows the nomenclature of a blade.

Leading and Trailing Edge Damage.— Random impact damage can be caused throughout the compressor rotor stages by FOD and DOD. The leading and trailing edge of an airfoil is the area of the compressor blade extending from the edge into the airfoil. You must assess both sides or faces of the airfoil when determining the extent of a given defect. If you observe a defect, estimate the percentage of damaged chord length. Observe the defect and the condition of the airfoil area around the defect. If the observed damage is assessed to be "object damage," the most difficult determination is the differentiation between cracks, scratches, and marks made by the passing objects. Cracks are usually tight in the airfoils, but the apex of the damage usually allows viewing into the airfoil thickness. This provides a direct inspection of the area around the crack You may have to use all the probes at varying light levels to determine the extent of the damage.

Tip Curl.— Compressor rotor blade tip curl is a random and infrequent observation. tip curl is usually the result of blade rub on the compressor case. Tip curl also can be the result of objects being thrown to the outer circumferential area of the flow path and then being impacted by the rotating blade tip (either leading or

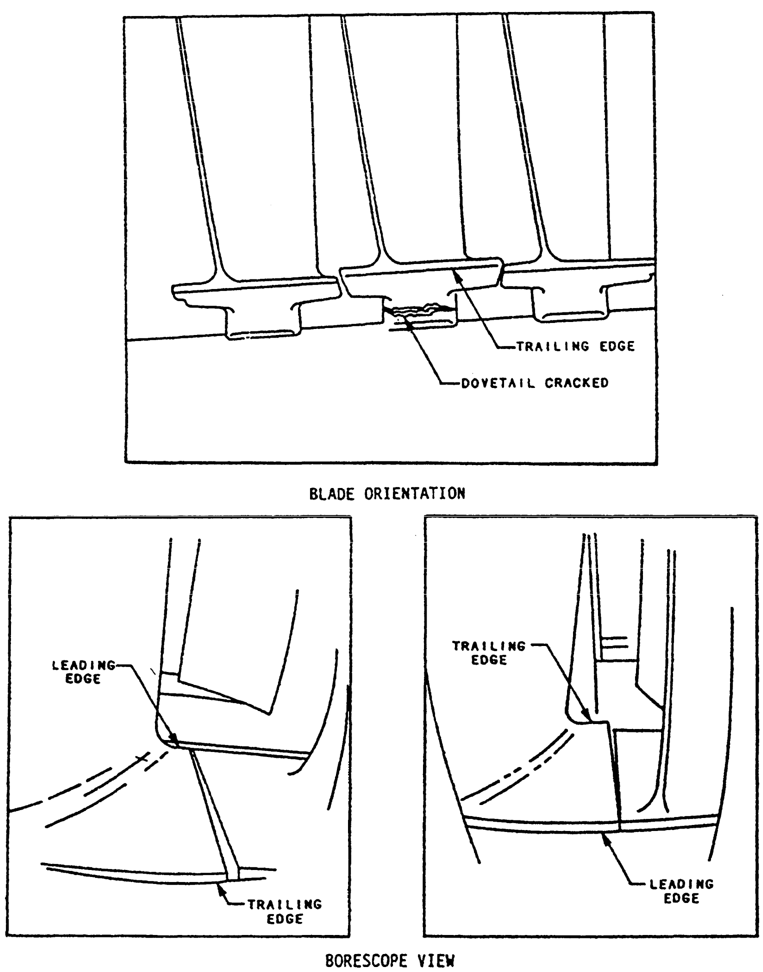


Figure 2-12.—Compressor blade leaners.

trailing edge). These curled tips are usually smooth in the bend area of the airfoil distortion. However, you should inspect the area at the change in normal airfoil for tears or cracks. When you report tip curl, estimate the percent of the chord length, the number of blades with curl, and the condition of the adjacent airfoil area. Record any evidence of impact and inspect for the origin of the impact. Always look at the adjacent blades for evidence of tip clang.

Missing Metal.— Missing metal from compressor rotor blade airfoils is a result of the progression of cracked or tom airfoils that release part of the airfoil into the flow path. Crack propagation in the root fillet area can result in the separation of the entire blade. Severe FOD or DOD may result in several random rotor and stator airfoils with missing metal. The inspection report should include the stage, the number of blades with missing metal, the amount, and the location on the airfoil. Estimate the percent of chord, the span of the airfoil that is missing metal, and the condition of the remaining airfoil.

Airfoil Surface Defects.— Surface defects are the result of object damage or adjacent blade interference (tip clang). Impacts in the center section of the airfoil are not common. Tip clang damage is the result of a blade leading edge tip contacting the adjacent blade tip at approximately one-third of the chord length forward of the trailing edge on the low-pressure (convex) side of the blade (fig. 2-13). This is the result of compressor stall and is observed in stages 3 through 6. You should report any observed defect on the airfoil surfaces in the inspection record. Your report should contain

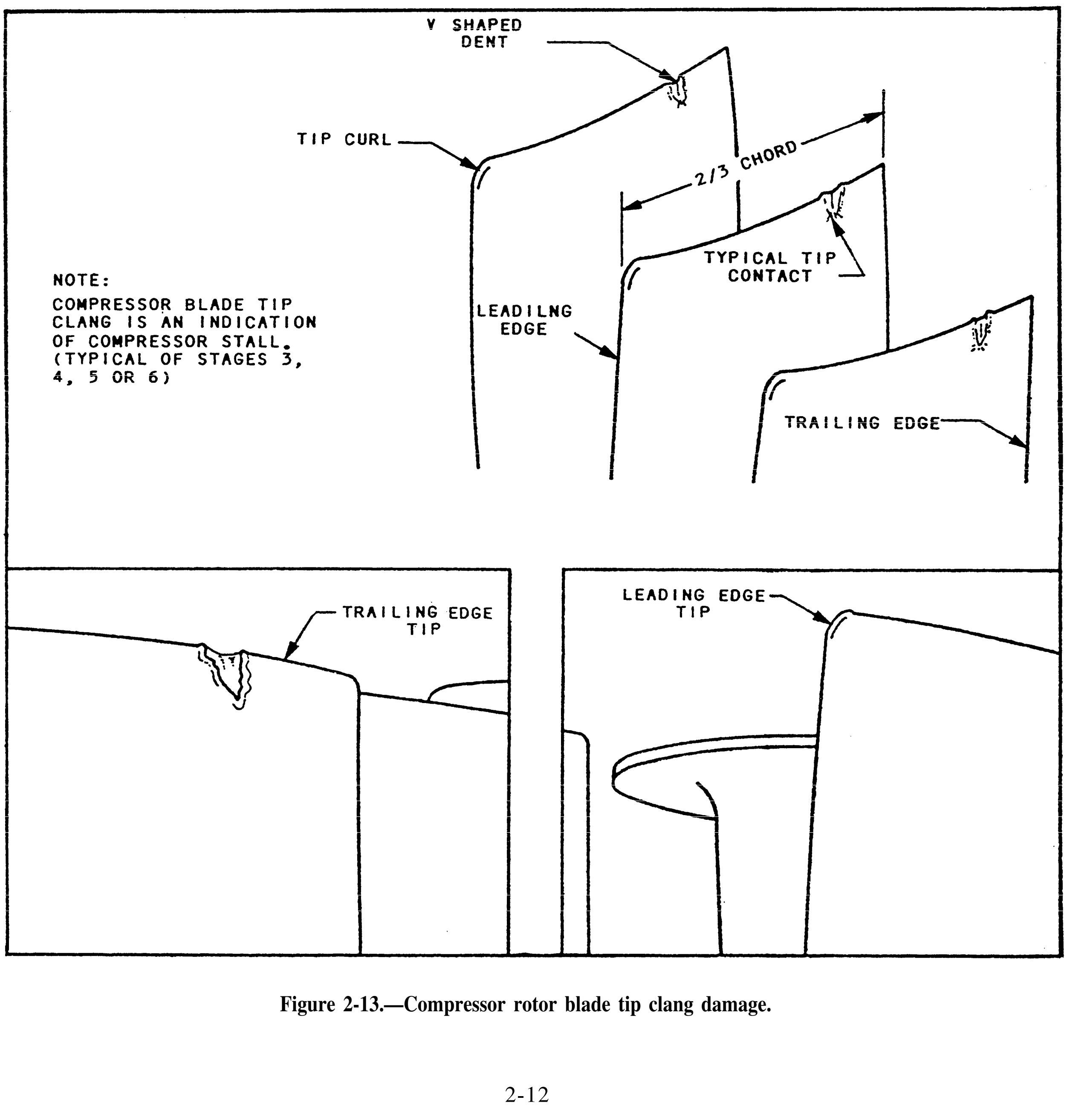


Figure 2-13.—Compressor rotor blade tip clang damage.

information relative to the stage, location on the blade (estimate the percent of chord and span), and the condition of the surrounding airfoil. You do not have to record the appearance of the defect (sharpness and contour). Compressor stall is one of the worst things that can happen to an engine. tip clang damage is difficult to spot and gives the appearance of minor damage. The V-shaped notch on the top of a blade caused by tip clang is only an indicator; it in itself is not the damage. The damage is at the blade root and normally cannot be seen. If a blade has been overstressed, it must be replaced.

Platform Distortion.— Compressor blade platform fretting or shingling (fig. 2-14) can be observed on some after stage blades. These distortions are the overlapping of one blade platform mating edge with the adjacent platform edge. When shingling is found, the platforms will be distorted and bowed (fig. 2-15). When the platforms are shingled, only the locking lug blades will exhibit this defect. Monitor this condition to see if a platform crack develops. Also look for missing pieces around the locking lugs. You must report and record any cracks in the platform. Be sure you have included the following information:

- The stage
- The number of blades

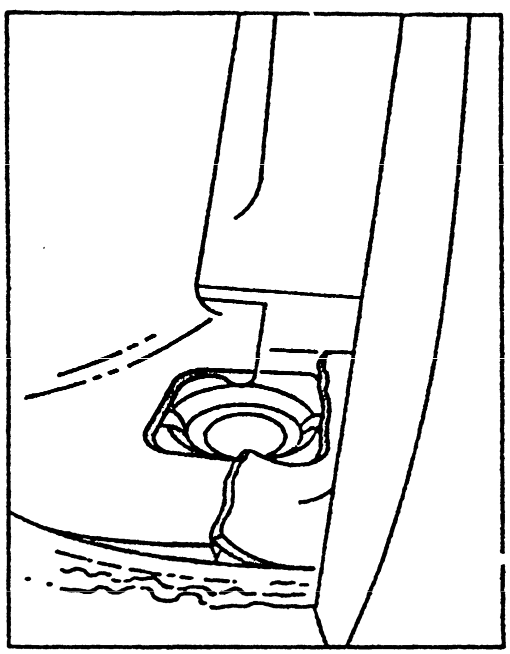


Figure 2-14.—Platform fretting or shingling.

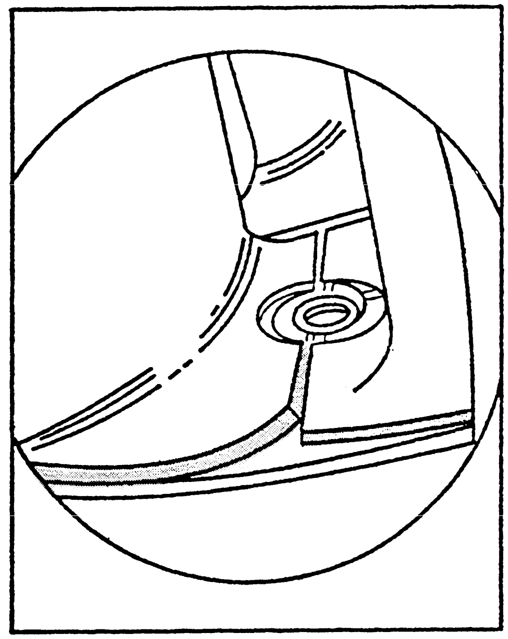


Figure 2-15.—Platform bowing.

- The spacing of the blade numbers separating the shingled blade platforms
- The platform gap observation (estimate gap as percent of circumferential span of the platform)
- The condition of the shingled edge (bent, fretted, or stepped as per table 2-1)

Midspan Shroud Wear.— Some stage 1 compressor blades show wear at the mating surfaces of the midspan damper shrouds. (See figs. 2-16 and 2-17.) Wearing of the tungsten-carbide wear coat causes the mating face contour to change from a straight line to a stepped line. This occurs at the after edge of the clockwise blade midspan (trailing edge) and the forward edge of the counterclockwise blade midspan shroud (leading edge). In the step area, some metal maybe turned or protruding from the midspan shroud mating line (mushrooming). This protrusion is indicative of wear-through. A missing pad on one face would initiate an accelerated failure of the mating surfaces.

BLADE DEPOSITS.— Compressor blades and stator vanes exhibit varying degrees of cleanliness. Variables such as air-inlet configuration, ambient atmospheric conditions, and air contaminants (chemicals, salt, dirt, water, and so forth) all tend to affect the surface condition of the compressor rotor and stator blades.

Aluminum Deposits.— Two areas in the compressor assembly are coated with aluminum, the

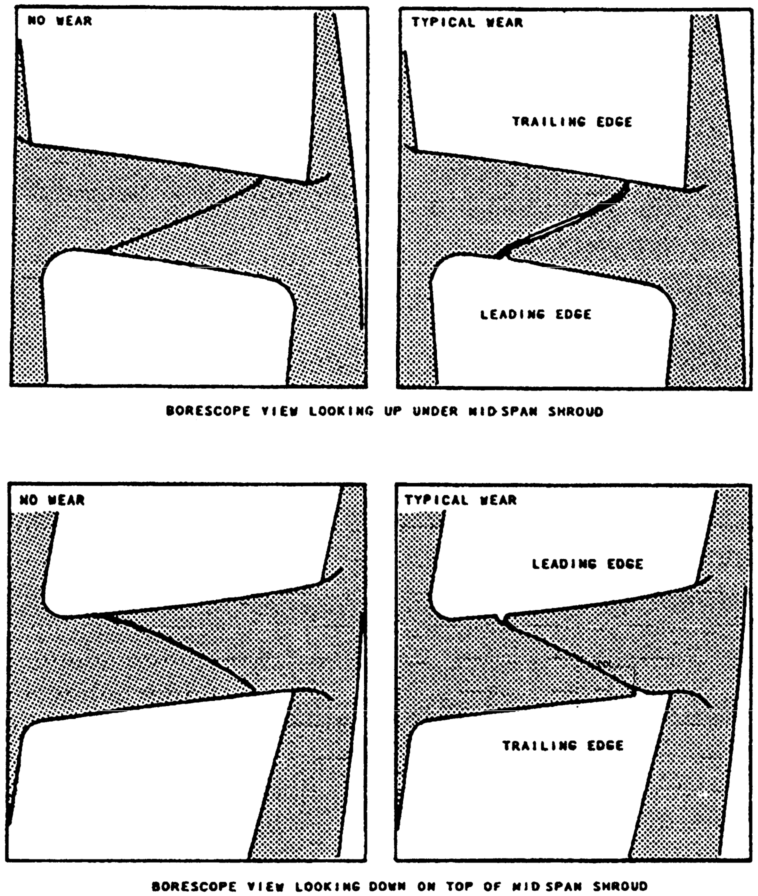
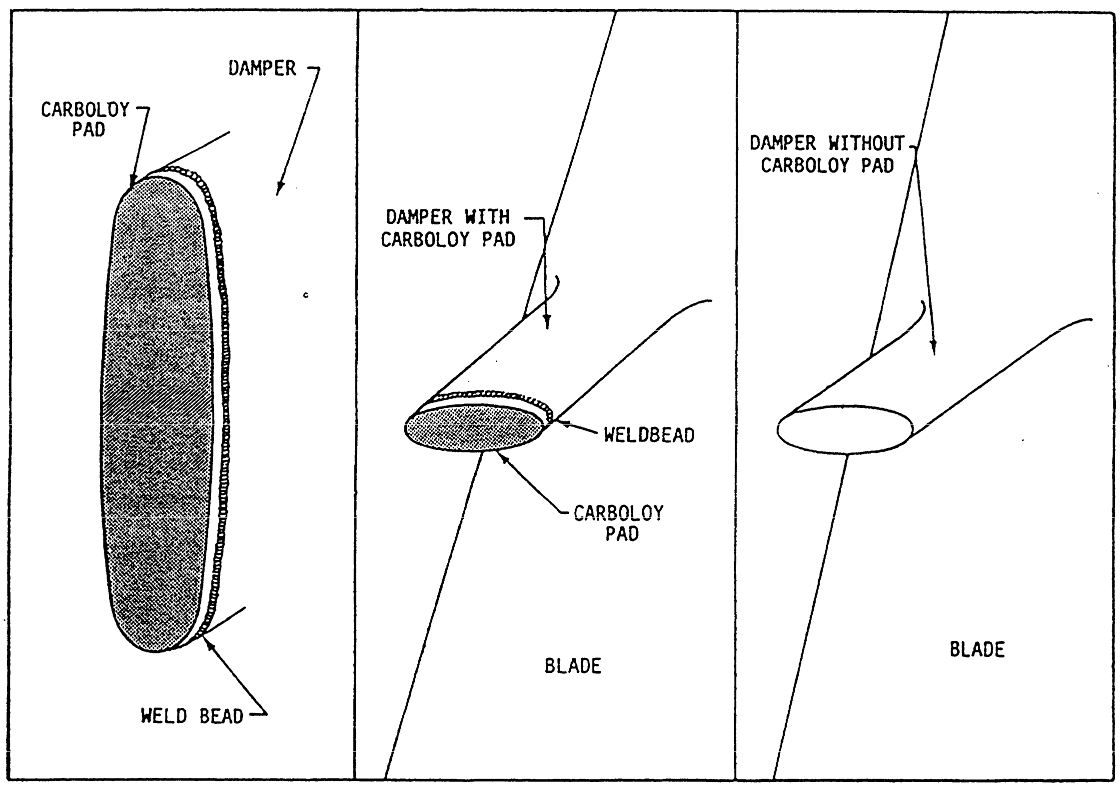


Figure 2-16.—Compressor blade midspan shroud wear.



l?igure 2-17.—Compressor blade midspan damper carboloy pad.

shrouding over the blade tips and the rotor drum area under the stator vanes. tip rubs of either the blades or the vanes will rub off the aluminum coating. As time is accrued on the compressor assembly, the after stages of the rotor release or flake the aluminum coating. This deterioration is a normal progression. Flaking occurs because of the differences in thermal expansion of dissimilar metals and the differences in the size and configuration of the various parts. The released aluminum flakes enter the airstream, impact the rotor blades or vanes, and splatter the airfoils. Aluminum splatter observed forward of stage 11 can be caused by object damage or aluminum flakes that are rubbed out of the compressor case coating. This condition requires a thorough inspection of the forward compressor stages.

Leading Edge Buildup.— Aluminum buildup on the leading edges of blades is usually observed in stages 11 through 16. The buildup changes the contour of the airfoil and can alter the stall margin. You should report the presence of leading edge buildup in the inspection report. This type of buildup may occur on low-time compressors. The compressor blades tend to "self clean" or lose this leading edge buildup as the assembly accrues time.

Airfoil Powdering.— Compressor rotor blades may have aluminum particles visible on the airfoils in varying degrees (from stage to stage). This powder is indicative of a possible compressor stall or a hard blade tip rub.

Combustion Section

Inspect the combustor for eroded or burned areas, cracks, nicks, dents, hot streaks, flatness of liners caused by hot spots, blocked air passages, and carbon buildup. If damage is found in the combustion section, it usually consists of a burn-through in the dome area adjacent to a fuel nozzle. The problem can usually be traced to a loss of film-cooling air caused by upstream debris or to a faulty fuel nozzle. Cracking is not normally a problem, but you should photograph and report any suspected or confirmed cracks. Carbon deposits around the fuel nozzles occur on all engines and are not considered serious. These deposits build up only on the venturi and swirl cup rather than on the shroud or discharge orifice. They do not usually interfere with the fuel spray pattern. If you find cracking, evaluate it to ensure that no pieces will detach and cause any secondary damage to the HP turbine. For reference to parts nomenclature used in the following section, refer to figure 2-11, sections B and C.

COMBUSTION SECTION DAMAGE.— In the following paragraphs, we describe some of the damage that you might find during a borescope inspection of the combustion section. Because the dark surfaces in the combustion section absorb light, you will need a 1,000-watt light source for a proper inspection.

Discoloration. — Normal aging of the combustor components will show a wide range of color changes. This is not a cause for concern. As operating time is accrued on the combustor assembly, an axial streaking pattern running aft of every other circumferential fuel nozzle will occur. On low-time assemblies, the coloration is random and has little or no information to aid you during the inspection. As operating time increases on the assembly, you will observe significant deterioration at the edges of the streaking patterns. Cracking will begin in the forward inner liner panels and will propagate aft. The axial cracks tend to follow the light streaks. Panel overhang cracking and liberation usually occur at the edge of the streaks.

Riveted Joints.— The dome band and the inner and outer liner assemblies are joined by rivets as shown in figure 2-18. The presence and condition of the rivet heads and rivet holes are easily assessed because of their position in relationship to the borescope ports. Record any missing rivets and torn or cracked hole edges.

Dome Assembly.— Distortion of the trumpets and/or swirl cups is random and occurs on high-time assemblies. Record the distortion (in percent) of the edge and/or span of the trumpet and the percent of circumference versus diameter of the swirlers.

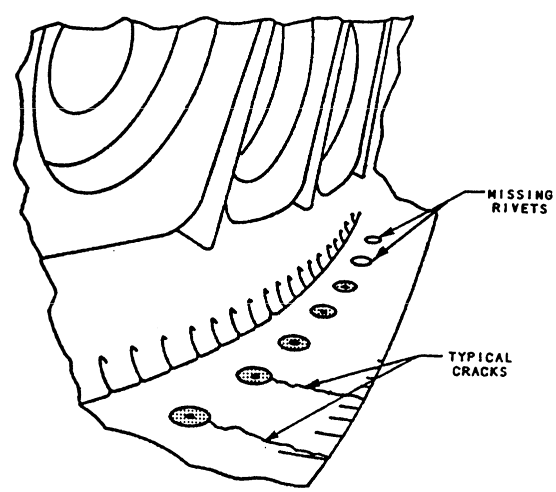


Figure 2-18.—Combustion liner dome rivet joint.

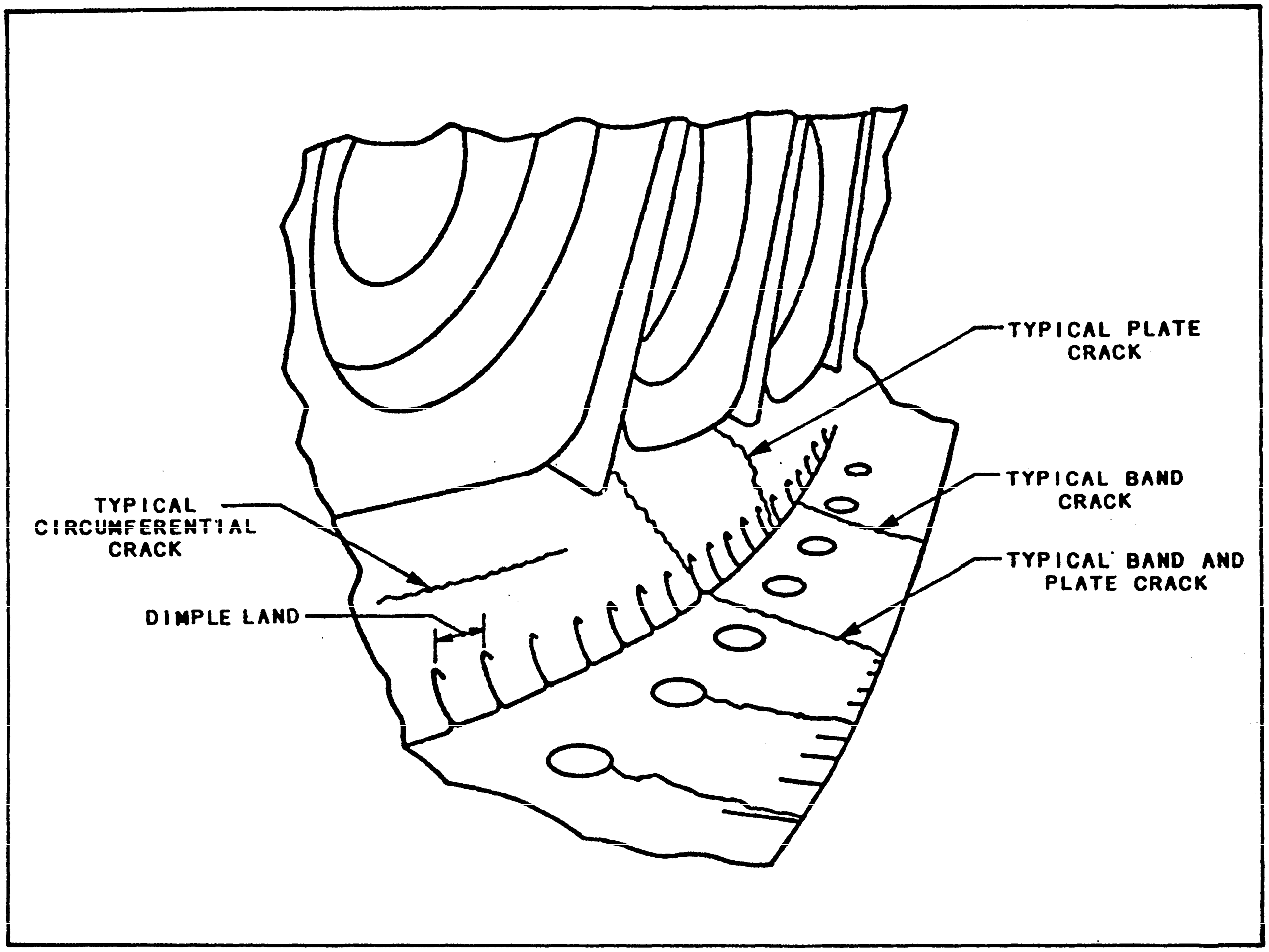


Figure 2-19.—Combustion liner dome band and plate cracks.

Cracking (fig. 2-19) in the dome band area occurs at relatively low operating time. Record the number of cracks and their relationship to one another. Indicate if these cracks are parallel, T-shaped, circumferential or angled to connect and separate part of the band, and so forth.

All the missing metal areas or burn-throughs (fig. 2-20) must be recorded. For the dome bands, estimate the magnitude by the number or partial/circumferential span of the dimples and axially by percent of span of the band overhang to the trumpet. Record the trumpet areas of burn-away and burn-through of the dome plate around the swirl cups. Burn-through in the combustor dome will reduce cooling flow to the HP turbine vanes. Monitor the HP turbine vane condition as burn-through progresses.

Igniter Tubes and Ferrules.— Inspect the two igniter locations (fig. 2-21) for the condition of the weld at the cutaway of the trumpet and the dome band. The ferrules are visible from these ports. Record the condition for evidence of cracking, loss of ferrule metal, or both. Cracking from the igniter tube aft to the panel overhang is common.

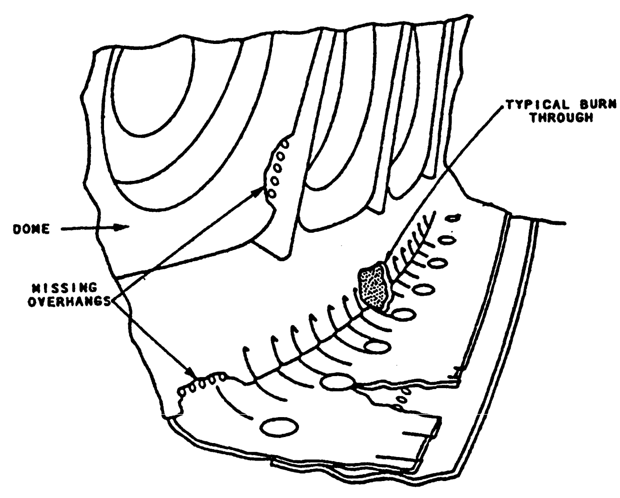


Figure 2-20.—Combustion liner dome bums and missing metal.

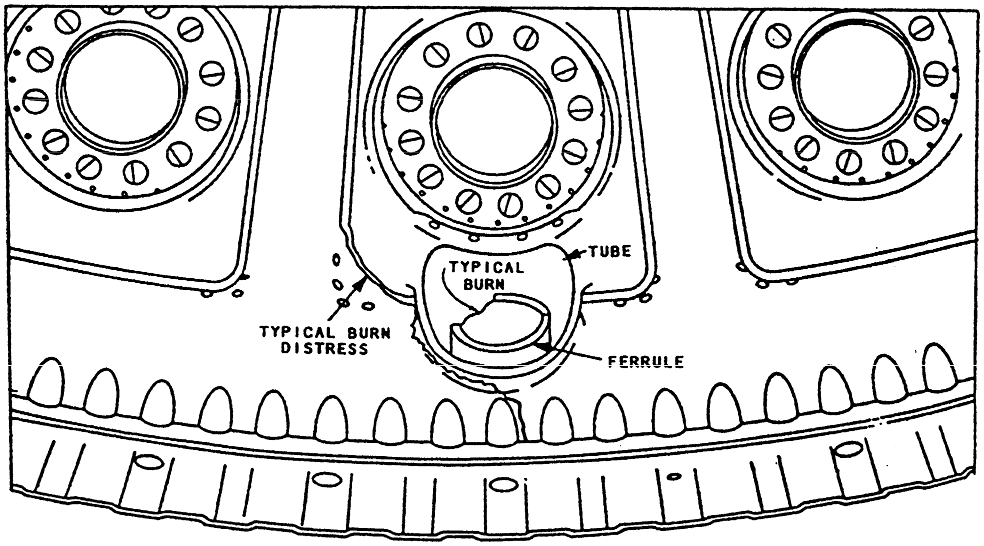


Figure 2-21.—Combustion liner dome igniter tube.

INNER AND OUTER LINER ASSEMBLIES.— You can inspect all areas of the inner and outer liner assemblies aft of the fuel nozzles by rotating and tilting the probe, and by varying the immersion depth. Some of the damage that you may find is described in the following paragraphs.

Circumferential Cracks.— Figure 2-22 shows an example of circumferential cracking on a high-time combustion liner. This type of cracking occurs over the area of the inner liner stiffening bands. The bands are circumferential stiffeners and are not visible when viewed through the borescope inside the combustor assembly. Before actual cracking, the thermal working of the liner shows stress lines. These lines will be visible in all panels. Take care to inspect for the presence of cracks, not merely lines. A crack will be open and the separation will show an edge. The distortion occurs so that the inner liner lifts up into the flow path and the outer liner bends down into the flow path. These irregularities are usually obvious when the liners are

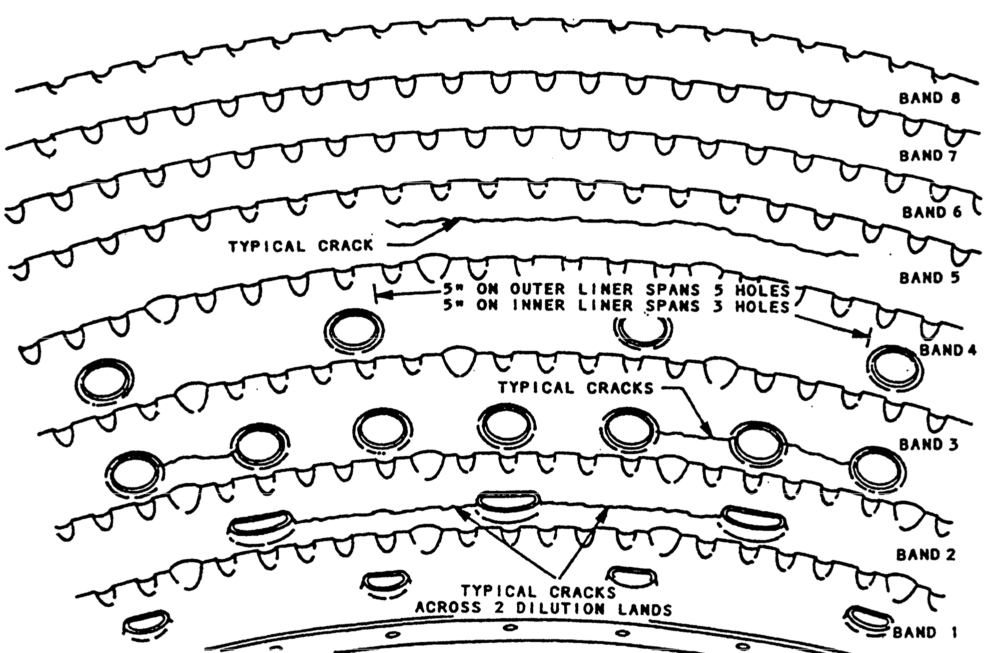


Figure 2-22.—Inner/outer liner circumferential cracks.

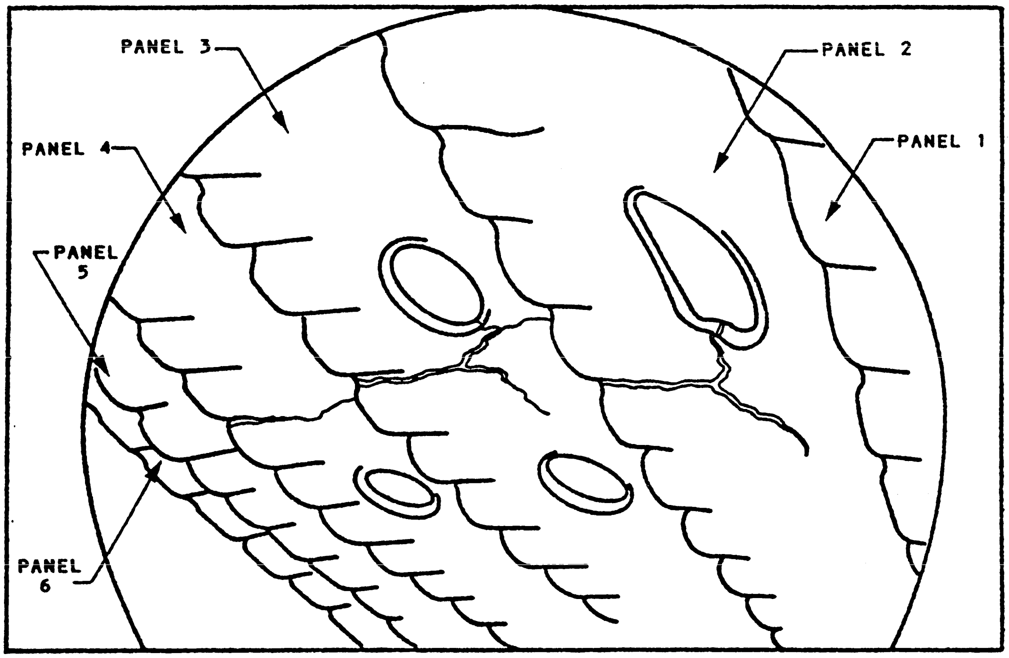


Figure 2-23.—Combustor inner liner cracks.

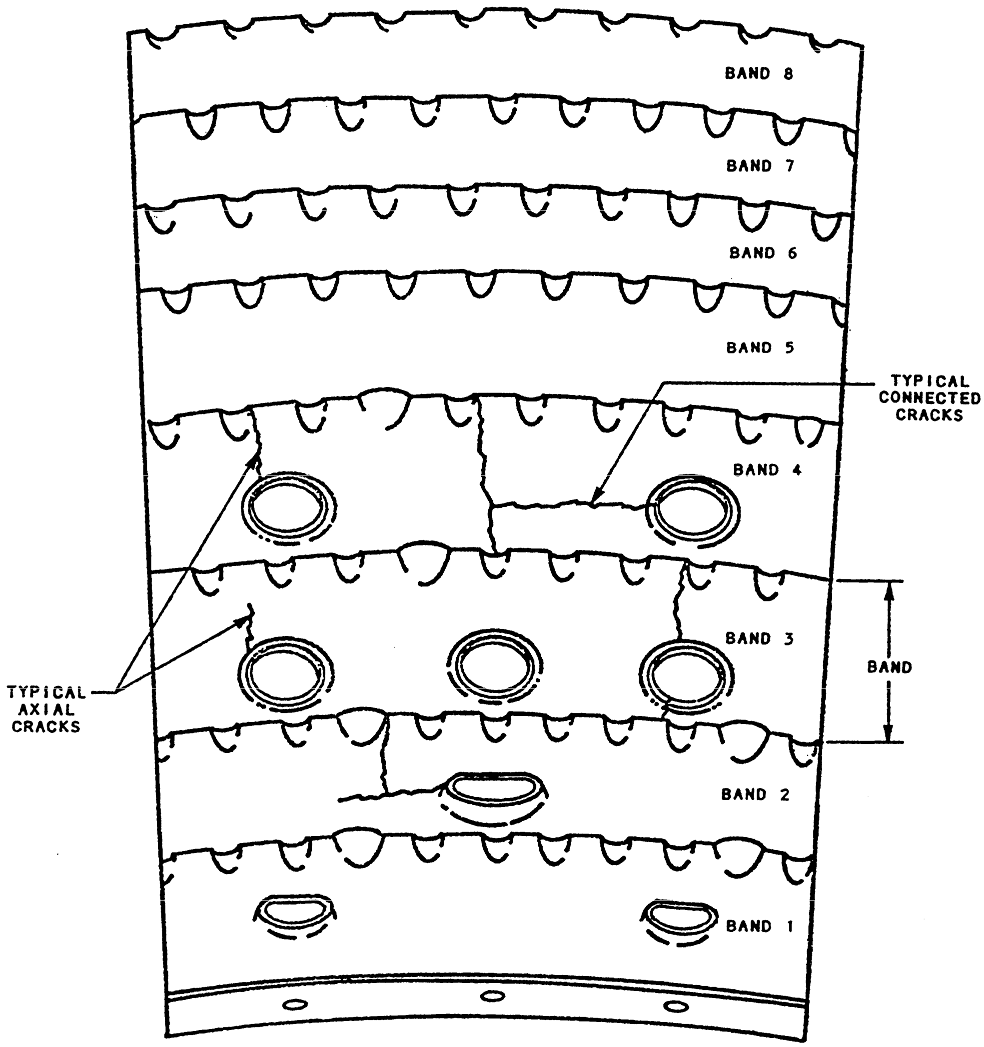


Figure 2-24.—Combustor liner cracks growing together.

viewed through wide angle probe No. 2. When circumferential cracking is observed, record the band number and the span of the cracking relative to the number of cooling/dilution holes. Use the diameter of the cooling holes as a comparative measurement gauge.

Axial Cracks.— Axial cracking usually starts at band No. 3 on the inner liners and propagates aft and forward. As operating time is accrued, these axial panel cracks grow into three-legged cracks as seen in figure 2-23. The edges of these cracks will separate and the corners will lift into the flow path. Inspect the areas aft and forward of these cracks, recording the axially separated cracks that show a tendency to grow together.

DOD is the primary cause of damage to the HP nozzle and turbine rotor elements. It is caused by pieces from the combustor liners cracking out of the panel overhangs and impacting with the rotating turbine elements. The most serious problem is the separation of a large section of liner that could cause significant damage. This usually occurs as a result of axial and circumferential cracks growing together as shown in figure 2-24. It is important to record the damage to adjacent areas of about 5 inches to either side of the damaged area. These areas can grow together and liberate large pieces of material. These circumferentially spaced, cracked areas are usually separated at every other fuel nozzle spacing along with axial color streaking.

Missing Metal and Burn-Through.— Inspect for the loss of metal at the panel overhang and the area between dimples (fig. 2-25). Bum-through of the liners is not common. What is common are the bluish-black slag areas that show roughness and appear to be oxidized. Inspect these areas carefully for T cracks because they will propagate and open up.

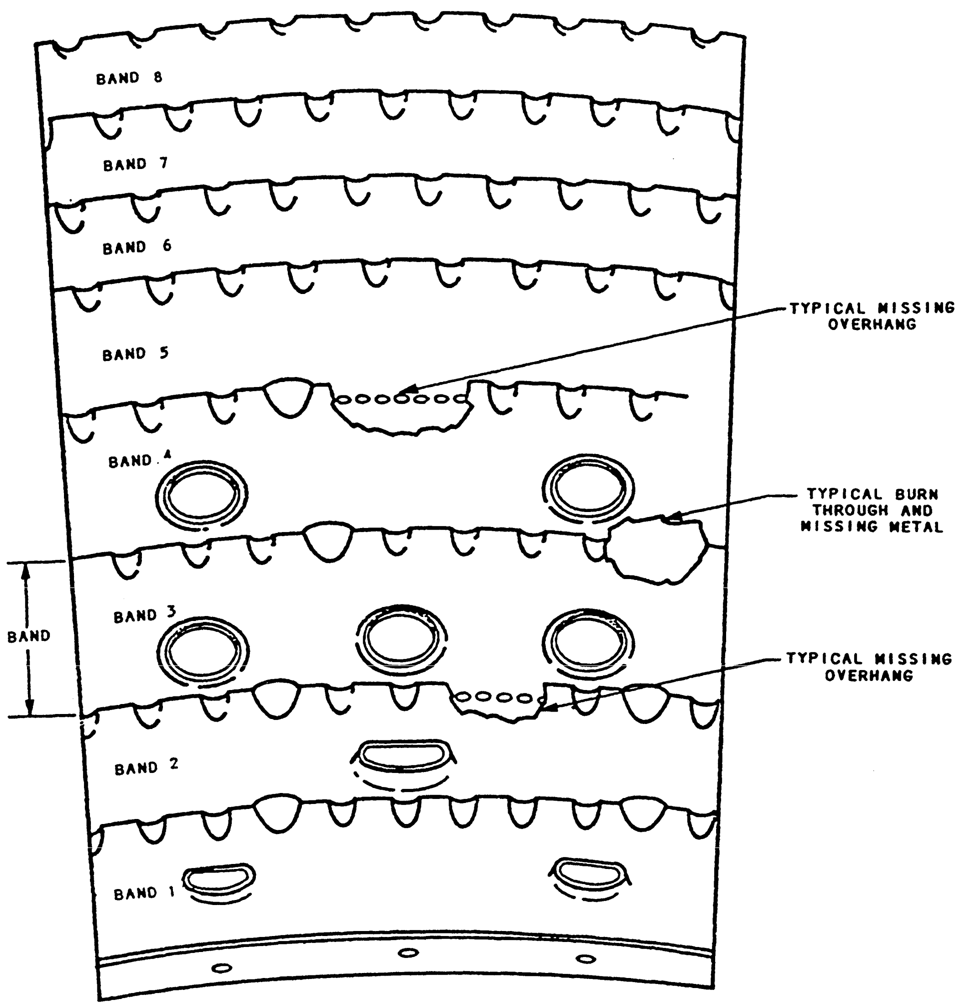


Figure 2-25.—Inner/outer liner burns and missing metal.

Distortion. — Distortion or bowing of the liner assemblies is extremely difficult to assess when viewed through the borescope. If an axial streak (gutter) is observed to be out of contour, estimate the relative distortion in terms of dimples spanned or in relation to the diameter of the dilution holes. If the distortion is present at the No. 1 band, estimate the contour change at the dome band relative to the panel.

HP Turbine

Inspect the HP turbine for eroded or burned areas, cracks or tears, nicks or dents, and missing blades. Knifing (erosion resulting in sharp edges) can occur on first-stage blades. The severity will vary according to the cleanliness of the turbine inlet air. Check for pitting on the leading edge near the root of the second-stage blading.

Cracking of the first-stage nozzle guide vanes is not very common, but photograph and report any suspected cracks. First-stage vane surfaces at the juncture of the inner and outer platforms have a tendency to corrode or erode. It would not be unusual for you to find several small penetrations in a vane platform during its service life. Most of these penetrations remain small and are not usually severe enough to warrant engine replacement. Record any such penetrations and regularly inspect them for any changes in size or quantity.

Vane HP (concave) surfaces will show gradual erosion with time, and the trailing edge slots will become elongated. When this degradation reaches maximum service limits, as noted on the PMS card or in the manufacturer's technical manual, the engine must be replaced.

HP turbine second-stage blades have a service life that is dependent upon operating conditions. Cracks are the major inspection criteria listed. You should document and report any confirmed cracks. The most common form of degradation is deposit buildup and erosion; this is not usually as severe as on the first-stage blades. The most serious form of damage that you may find in this area is pitting in the root area, which you must document and report. For reference to the parts nomenclature used in this section, refer to figure 2-11, sections D and E.

HP TURBINE NOZZLE DAMAGE.— The first-stage turbine nozzle vanes are inspected simultaneously with the combustor and fuel nozzles. The following paragraphs describe the common damage you may find during the borescope inspections.

Discoloration.— Normal aging of the HP turbine nozzle stage 1 vanes will result in coloration changes as operating time is accrued. There is no limit relative to discoloration of HP turbine nozzle vanes.

Oxidation and/or burning of the vane areas is accompanied by dark areas silhouetting the initial distress. Cracks are shrouded in dark patches adjacent to the defect. Usually the distress starts as a crack, followed by oxidation of the shroud adjacent to the crack Impact damage usually shows as a dark spot on the leading edge.

Leading Edge Damage.— This type of damage can be found between the forward gill holes on the concave and convex side of the leading edge.

- Axial cracks form around the leading edge. Estimate the percent of span of the leading edge or span relative to the nose cooling hole rows to determine the crack length.

- Burns and spalling on the leading edge should not be construed as coloration only, but must have actual metal oxidized (surface metal loss), but no holes through the leading edge. Estimate the area boundaries by the nose cooling holes spanned both radially (up and down the leading edge) and axially (around or across the leading edge). Record the number of vanes affected.

- Blocked cooling air passages on the leading edge is another type of damage. If multiple hole blockage is observed, record the separation of the open cooling holes and the number of adjacent plugged holes.

Airfoil Concave Surface.— Radial cracks run spanwise in the vane airfoil surface (up and down the vane). Record the relative chord position of the cracks. Record the relation of axial cracking versus radial cracking, such as axial and radial cracks that intersect or join at the second row of gill holes. The intent of the service limits are to preclude the liberation (break-out) of pressure facepieces.

Other Airfoil Area Defects.— The following paragraphs describe other airfoil area defects that you may find during the inspections.

- Burns and cracks on concave and convex sides (charred). Record the area and length, estimate the length relative to the leading edge area (gill hole to gill hole and spanwise by span of cooling or gill holes). Estimate the surface damage relative to separation of gill hole rows and radially by gill or cooling holes.

- Craze cracking. These cracks are superficial surface cracks, caused by high temperature. They are random lines that are very thin in appearance with tight lines (no depth or width to the cracks). There is no limit against this condition.

- Nicks, scores, scratches, or dents. These defects are allowed by the service limit and may "be present on any area of the nozzle vanes.

- Cracks in the airfoil fillet at the platform. There is no limit restricting these cracks, except at the leading edge area.

- Metal splatter. Aluminum and combustor liner metal, when liberated by the compressor or combustor, frequently splatter the surface areas of the stage 1 HP turbine nozzle vanes. There is no limit for these deposits; however, abnormal amounts of this splatter is reason to inspect the compressor.

Platforms.— Cracking in the HP turbine nozzle stage 1 platforms is difficult to see from the combustor borescope ports. When this area is viewed through port No. 12, extreme magnification is afforded even with probe No. 2. This is due to the closeness of the surface to the distal end of the probe. Record the origin and end of the cracking and assess the magnitude using trailing edge slots and gill hole rows for radial and axial dimensions.

Nicks, scores, scratches, and dents on platform surfaces are again masked from the combustor ports, except for the forward areas. Viewed via port No. 12, the area is magnified. Record the magnitude of the defect using the geometry of the trailing edge, gill hole rows, and gill hole separation for comparative dimensions.

You must record burns on vane platform areas and use probe No. 1 to assess the conditions. If a burn-through occurs, the inner and outer surface edge of the platform should be seen. This difficult assessment can be done with the aid of a fiberscope. Any incomplete or doubtful evaluation should be the subject of a followup check after a specified amount of operating time.

HP TURBINE BLADE DAMAGE.— When inspecting the HP turbine blades, you should use probe No. 2 with the 150-watt light source. The following paragraphs describe some of the damage you may find.

Cracks in the Leading Edge.— The leading edge of the stage 1 turbine rotor blades is the area forward of the gill holes. Cracks in the leading edge can be caused by DOD impact (combustion liner pieces) or thermal stress. An indication on the leading edge open enough to show depth is defined as a crack. Some conditions may mislead you in the determination of the presence of cracks. Dirt and debris buildup inlayers on the leading edge, as shown in figure 2-26, are not cracks. When this buildup begins to flake off, the edge of the area where the flake came off causes visible lines. These lines are irregular and appear to be cracks. The other common point of cofusion on leading edge cracks is on the convex side of the leading edge tip area. This area is subject to "scratching" by the small pieces of combustor metal that pass through the HP turbine.

Cracks in the Trailing Edge.— The trailing edge is the flat surface with cooling holes that forms the after edge of the blade airfoil. Trailing edge cracks are difficult to see, but if a crack is suspected, use probe No. 1 for increased magnification. Record the location relative to a cooling hole and the magnitude of the crack. Record any plugged trailing edge cooling holes.

Cracks in Concave and Convex Surfaces.— The airfoil surfaces are the areas aft of the gill holes back to the trailing edge. The tip area is further restricted to that area above the tip cap. When you evaluate the airfoil serviceability, do not consider the tip as a part of that area. Cracks in the airfoil surfaces are very tight, but can readily be seen with probe No. 2. Airfoil surface cracks are irregular in edge appearance and are not usually confined with streaks, which are usually straight in appearance. Record the area by the percent of span or gill hole spacing equivalent for location and magnitude of the cracking. For axial position, use an estimate of percent chord and the position relative to the tip cooling film cooling holes.

Cooling Hole Blockage.— The HP turbine rotor stage 1 blades are film cooled by air that flows out of the cooling holes. Report plugged holes relative to the number of blades affected and the position and number of plugged holes. Ensure the correct callout of the holes (such as the nose cooling, convex gill, tip film cooling holes, and so forth.)

Distortion.— Heavy impact damage to the leading edge of the blade usually results in distortion. When the impact is severe enough, cracking and/or tearing of the leading edge, adjacent to the impact area, occurs.

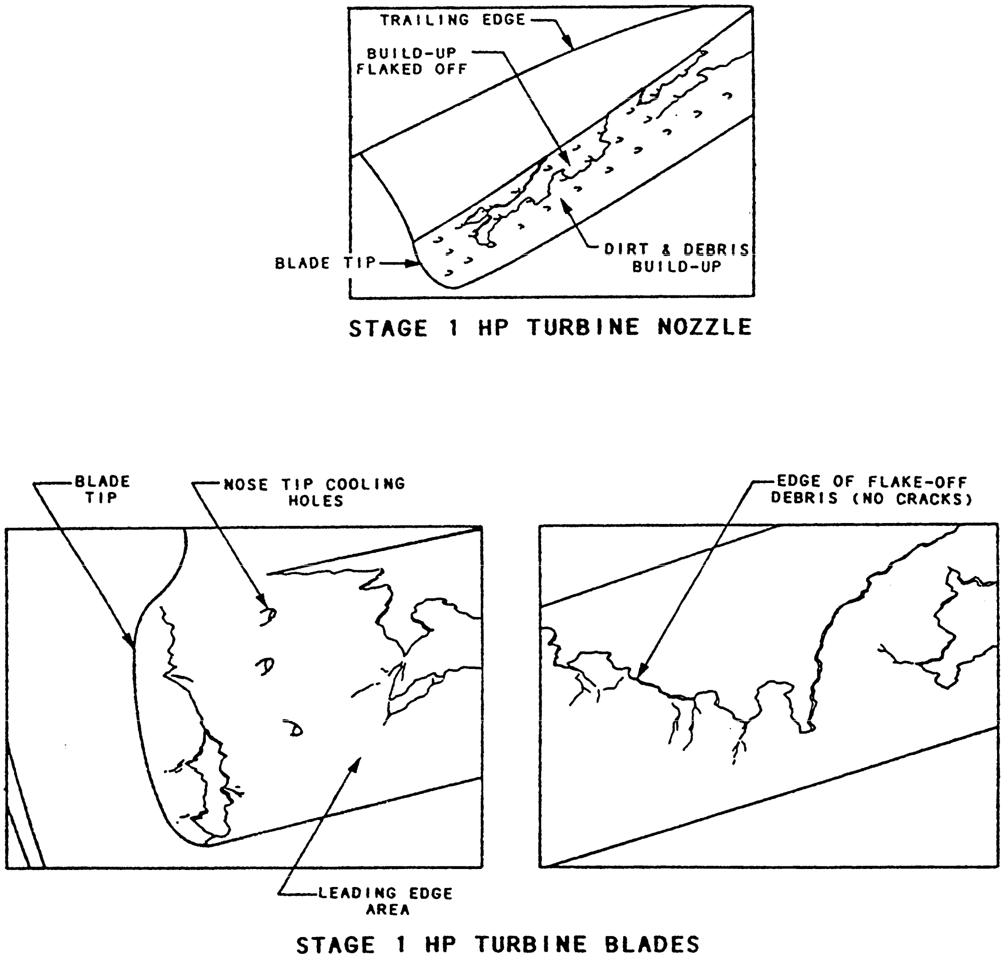


Figure 2-26.—HP turbine blade flaking and buildup.

Record the magnitude and span location relative to the number of gill holes spanned. Estimate the out of contour as percent of the leading edge frontal area width or relative to the lateral spanning of the leading edge cooling hole rows.

Blade Tip Nibbling.— The HP turbine rotor stage 1 blade tip nibbling is associated with hot running engines. Momentary overtemperature operation (such as experienced during compressor stalls) has exhibited this type of deterioration. This area of the blade is above the tip cap and located about two-thirds of the chord aft from the leading edge. Figure 2-27 shows a typical "nibbled tip" as a result of a severe stall.

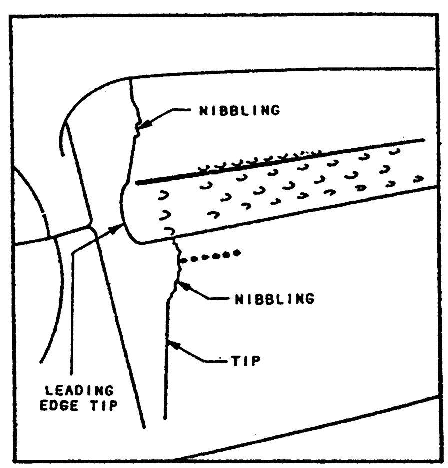


Figure 2-27.—HP turbine blade tip nibbling.

Blade Leading Edge Impact Damage.— Figures 2-28 and 2-29 show an impacted and distorted leading edge of a stage 1 HP turbine rotor blade. (Note the cracking condition leading from the impact area into the airfoil surface.) The critical part of this type of damage is the axial or chord wire cracking. If this cracking progresses from the impacted damaged area into the convex or concave airfoil surface, the damage can be severe.

HP Turbine Blade Coating Failure.— The HP turbine protective coating is the key factor in the service

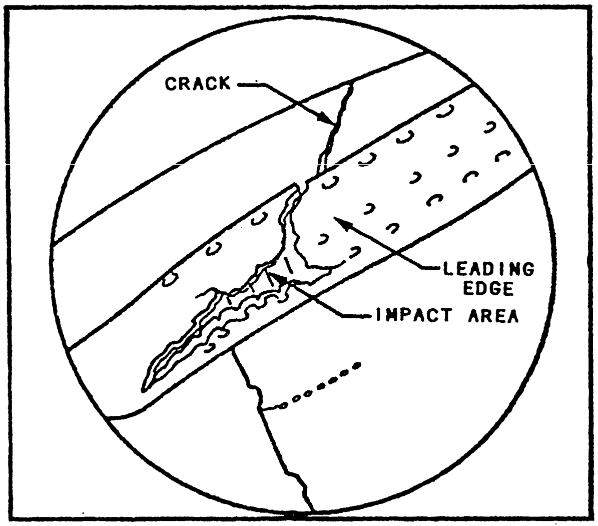


Figure 2-28.—HP turbine blade impact damage.

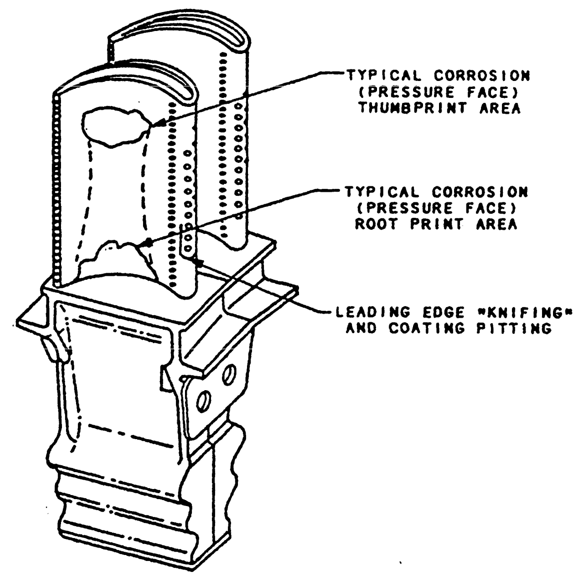


Figure 2-30.—HP turbine rotor stage 1 blade—areas of severe corrosion after extensive operating time.

life of an LM2500 GTE. The combined effect of film cooling and protective coating will extend the service life. Coatings are thinly and uniformly applied by a vacuum film deposition process. Coatings do not usually cause problems by chipping, peeling, or flaking. The normal failure mode is usually by pitting, rub off, or nicks and scratches. Occasionally a bubble will occur in the surface coating during the coating process. If a bubble occurs, it will be tested at the coating facility to ensure that it cannot be rubbed off the surface. These bubble imperfections pose no problem to the engine. If the bubble area of the coating fails, you should monitor that area to determine any further deterioration. Development and testing of new coatings that are highly resistant to corrosion and erosion are in progress. The present blade coating for single shank HP turbines is designated BC23. However, twin shank HP turbine blading presently have blade coating BC21. As they become serviceable by an area Naval Aviation Depot (NADEP) these blades will be replaced with blades coated with BC23. Use of these newer blade coatings can significantly extend blade service life.

HP TURBINE BLADE FAILURE MODES.— Failures that you may observe during a borescope inspection include the following types:

- Corrosion of the coating. This appears as pitting of the coating primarily in the 80-percent span midchord region of the concave airfoil (thumbprint) side and the 20-percent span midchord region (root print) (fig. 2-30). This corrosion/erosion has not been found on blades coated with BC23.

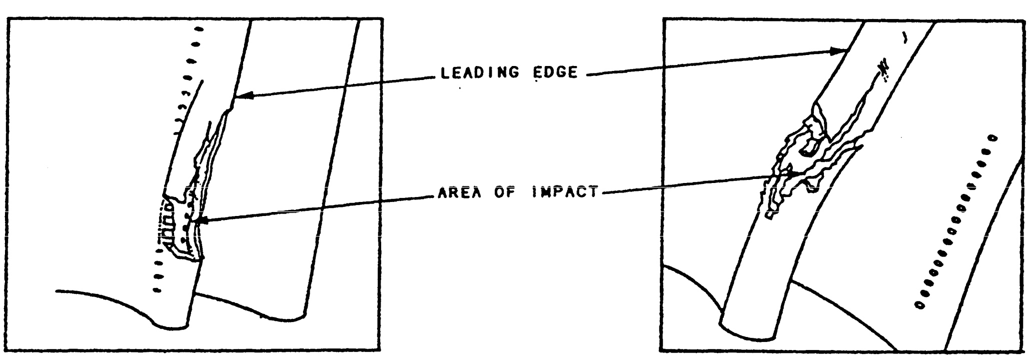


Figure 2-29.—HP turbine leading edge impact damage.

- Cracks in all areas of the blade, including radial cracks in the tips. Cracks generally start at the cooling holes.
- FOD/DOD, including nicks and dents.
- Aluminum spattering that appears as metallic deposits on the blade. This results from compressor tip rubs.
- HP turbine blade tip rubs. This results in coating removal and tip damage.

TURBINE MIDFRAME DAMAGE.— The following paragraphs describe damage that you may find when inspecting the turbine midframe.

Discoloration. — On low-time liners, the coloration is random and sometimes appears as a wavy surface. The coloration is random both axially and circumferentially. On high-time liners you may observe some axial carbon streaking. There are no service limits on discoloration

Liner Cracking.— Initial deterioration of the turbine midframe liners occurs at the forward inner liner flange in the form of axial cracking. It is difficult to determine the magnitude or length of a crack in this area. The area is immediately aft of the HP turbine stage 2 blade platforms. Small tight cracks will probably not be noticed. Of primary interest is that there are no cracks with visible turned up edges. If cracking is observed in the forward inner liner flange, you can use a fiberscope for a closer look to establish the extent of the crack and the adjacent area condition. Cracking can also occur around the leading edge weld beads on the strut fairings at both the inner and outer liner areas.

Liner Distortion.— Turbine midframe distortion most commonly occurs in the 10 to 12 o'clock area of the outer liner forward flange. The only relative gauge available for comparative assessment (roundness/contour) is the HP turbine stage 2 blade tip arc and the stage 2 shroud contour. A fiberscope is recommended for the final assessment of any suggested distortion of the liner. You will need a guide tube to position the fiberscope.

Power Turbine

The most common problem in the power turbine section is usually a loss of the hard coat on the tip shroud. Notch wear and subsequent blade bending are direct results of tip shroud hard coat loss. Notch wear and blade bending will ultimately lead to fatigue failure of the airfoil. The actual loss of the hard coat cannot be confirmed through the borescope. It can be confirmed by removal of the upper case and actual physical inspection of the tip shrouds. You can seethe symptoms through the borescope by looking at the notch with probe No. 1. Uneven notch wear may indicate loss of the hard coat. You should carefully inspect for any transverse cracks in the blade airfoil around the 10 percent span. <u>Any cracking is cause for replacement of the power turbine.</u>

The power turbine first-stage blades also have a history of deposit buildup that leads to rotor unbalance and excessive vibration. For reference to parts nomenclature used in this section, refer to figure 2-11, sections F and G. Power turbine damage that you may find is described in the following paragraphs.

CRACKS IN BLADES.— Inspect the total airfoil, platform, and tip shrouds for evidence of cracks. If you suspect a specific area, use the high-magnification probe. You will see a limited amount of the stage 1 blading when viewing aft from the turbine midframe liner inspection ports. You can see more detail with a fiberscope or by viewing forward from the turbine exhaust duct. Cracks will show depth and under magnification will show edge material definition. Be sure to distinguish cracks from false indications such as smears and carbon streaks.

NICKS AND DENTS.— Record these defects in relation to the percent span and percent chord for magnitude and location on the blade. Record also the condition of the blade material adjacent (at the extremities of the defect) to the observed defect. Record any cracking or sharpness of nicks or dents. Investigate smooth impact deformities to determine the origin of damage.

WEAR.— Inspect LP turbine rotor blade tip shroud interlocks or circumferential mating surface for wear at stage 1. Wear is observable and will appear as shown in figure 2-31.

DIRT, COLORATION, PITTING, AND CORROSION.— High-time LP turbine rotor assemblies may show airfoil surface irregularities that could be dirt accumulation, carbon buildup, surface pitting from particles in the gas stream, or corrosion of the blade material. Dirt and coloration are of little concern; however pitting and corrosion may be significant.

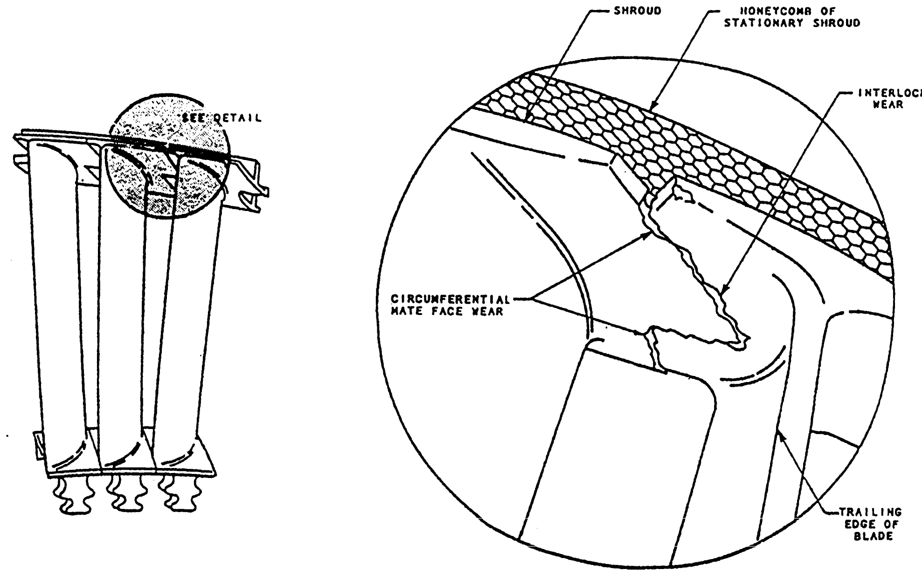


Figure 2-31.—Power turbine shroud wear.

Evaluating Physical Size

You determine physical size in several ways. By using dimensional data in the manufacturer's technical manual, you can estimate size by making a comparison to a known dimension in the field of view. Another way you can evaluate size, particularly in regard to cracks, is to use a lockwire of a known diameter. The lockwire is inserted into the field of view and placed next to the crack for size comparison. When using this method, you should be sure that the lockwire cannot fall inside the engine. Using an absolute reference for size, such as the lockwire or a known dimension, is more reliable than estimating the size through a borescope.

Color Evaluations

During inspections, you can observe deposits or various forms of deterioration. Table 2-3 is an engine color chart that lists the color of common deposits and

Table 2-3.—Engine Condition Color Chart

COLOR	LOCATION	INDICATION
Blue, blue-green	High-pressure turbine	Sulfidation, corrosion
Shiny black	High-pressure turbine	Fuel residue, wet
Dull black	High-pressure turbine	Fuel residue, dry, coking
White	High-pressure turbine	Water-wash detergent
White	High-pressure turbine	Sea salts
Brick red	High-pressure turbine	Iron oxide (rust)
Tan	High-pressure turbine	Silica (sand)
Black	Compressor	Grease (dirty)
Metallic white	Compressor	Aluminum oxide
Grey (light or dark)	Power turbine	Deposit buildup
Grey (dark)	High-pressure turbine	Oxidation of coatings

conditions. This information will aid you in interpreting what you see by evaluating the color of the area or component. Color photographs taken through the borescope are an effective method to record the results of an inspection.

It is difficult to make accurate color interpretation. Table 2-3 is only an aid. The only color indication that might give immediate cause for concern is aluminum oxide splatter in the hot section of the engine. Other colorations are normal and do not limit the service life of the engine.

WATER WASHING

Water washing an engine as a prerequisite to borescope inspections is the best way to achieve an accurate evaluation of an engine's condition. Dirt and soft carbon deposits may obscure small cracks and pitting that could be missed if the engine were dirty. For more information on borescoping procedures, you should consult the technical manual for *Internal Inspection and Evaluation of Marine Gas Turbine Engines (Model* LM2500), NAVSEA S9234-D1-GTP-010.

REPORTING INSPECTION RESULTS

Unless a discrepancy is found, you do not have to enter routine borescope inspections in the Marine Gas Turbine Engine Service Record (MGTESR). However, if the inspection was conducted as a troubleshooting procedure due to an engine malfunction or was ordered by a higher authority, you must log the inspection and note the findings. You must evaluate and report all major damage or exceeded service limits to NAVSEA. If the damage or wear is extensive, the engine must be replaced. Further information on the MGTESR is provided in chapter 1 of this TRAMAN and *Naval Ships' Technical Manual (NSTM),* chapter 234, "Marine Gas Turbines."

TROUBLESHOOTING

As a GS supervisor, you will find that successful troubleshooting is a rewarding experience. Proper use of the manufacturer's technical manual will enhance your professional abilities and result in getting the job done right the first time. This section discusses the use of the troubleshooting sections of the LM2500 GTE technical manual.

TROUBLESHOOTING TECHNIQUES

Troubleshooting is a systematic analysis of symptoms that indicate an equipment malfunction. These symptoms usually appear as deviations from the normal parameters. You must be able to recognize normal operating conditions to recognize abnormal operation. If you have a thorough knowledge of equipment systems and use logical reasoning, you will be able to solve most troubleshooting problems with little difficulty. The basic methods used during mechanical and electrical/electronic troubleshooting are as follows:

- Be sure you know the normal operating conditions (be able to recognize a problem).
- Find out everything about the nature of the malfunction. Write down all the symptoms and see if they follow an identifiable pattern.
- Check the obvious:

—Blown fuses

—Tripped circuit breakers

—Faulty alarms

—Loose connectors and cannon plugs

—Switches in the wrong position

—Burned-out lamps

—Physical damages

—Last PMS or maintenance procedure performed

—System alignment

LM2500 TROUBLE ISOLATION

The trouble isolation section (volume 2) of the LM2500 technical manual contains three chapters with troubleshooting information that will aid you in isolating faults and malfunctions in the LM2500 GTE and its ancillary equipment. The manual presents troubleshooting procedures in fault logic diagrams, fictional dependency diagrams (FDDs), and signal flow diagrams.

Fault Logic Diagrams

These diagrams are based on a fault indication observed during troubleshooting. The diagrams comprise a branching series of questions pertaining to fault isolation. Each question pertains to further observation or measurement, and results in a yes or no answer. In this way, the possible functional area of the fault is progressively narrowed. Tolerance values are presented in those instances where a definitive yes or no is not obtained. This progression and elimination will allow you to isolate the functional area of the equipment containing the fault. After lessening the possible causes, the diagram then refers you to the portion of the manual needed to complete the fault isolation and repair. Each diagram includes, or makes reference to, the information necessary to establish the test or operating conditions required for starting the fault isolation procedure. The following three types of blocks are used in fault logic diagrams.

- Shaded blocks (right and bottom border lines shaded) contain questions that may be answered from observation, without changing the test setup and without special equipment

- Single-line blocks contain questions requiring measurement by special setup of external test equipment

- Double-line blocks (conclusion blocks) list the fictional area within an equipment unit that is the probable source of the malfunction and reference a procedure or another diagram for further isolation or correction of a fault

Functional Dependency Diagrams

The FDDs are used to support troubleshooting of the gas turbine electronic power control system. An FDD is a block diagram that illustrates the fictional dependency of one test point (or circuit) upon another.

Signal Flow Diagram

The signal flow diagram depicts the circuitry for each of the main functions of the circuit that you are troubleshooting. The notes preceding the signal flow diagram contain instructions for establishing operating conditions and connecting test equipment that is required for measuring the circuit parameters. For more information on troubleshooting the LM2500, refer to *Propulsion Gas Turbine Module LM2500,* volume 2, part 1, NAVSEA S9234-AD-MMO-030/LM2500.

ECSS TROUBLESHOOTING PROCEDURES

This section will provide you with some simple, but helpful, information when isolating a fault in engineering control and surveillance system (ECSS) equipment. Remember, many of the tips previously mentioned are still applicable for electrical/electronics troubleshooting. To successfully troubleshoot any piece of ECSS equipment, you should keep the following five steps in mind:

1. Energize the equipment to full operation using the appropriate EOP steps and equipment lineups.
2. Identify the faulting functional area.
3. Locate the test and signal flow diagram relating to the faulting component.
4. Using the correct troubleshooting diagram, isolate the malfunction to the faulting replaceable or adjustable subassembly.
5. When a fault has been found to be in a specific replaceable subassembly, refer to the appropriate technical manual chapters for connective maintenance instructions.

When using the signal flow diagrams for troubleshooting, you should begin at the malfunctioning component and work back to the original signal source. By starting at the source of the problem, you should be able to identify and correct the problem in an efficient and timely manner.

TROUBLESHOOTING DIAGRAMS

The types of troubleshooting diagrams and charts used are the

- signal flow diagrams (description is given in previous section),
- power distribution diagrams,
- logic flow charts,
- timing diagrams,
- interconnecting diagrams,
- troubleshooting functional dependency diagrams, and
- the circuit card locator and function information plates.

Power Distribution Diagrams

Power distribution diagrams show the distribution of the primary ac power, secondary ac power, and the dc power from the input to the various components.

Logic Flow Charts

Logic flow charts have the event sequences as determined by the logic circuits. The charts are, in effect, pictures of the logic equations. They maybe used along with the logic equations found in chapter 3 of the S9234-series technical manuals.

Timing Diagrams

Timing diagrams are for all significant timing relationships. The diagrams show the exact timing relationships and the origin of all significant timing signals.

Interconnecting Diagrams

Interconnecting diagrams show the internal cabling between the consoles and the electronic enclosures. These diagrams identify the cabling and components by reference designations.

Troubleshooting Functional Dependency Diagrams

Troubleshooting fictional dependency diagrams (TFDDs) show the fictional dependency of one circuit upon another. The TFDDs are setup in pyramid fashion. The vertical chains of boxes show contributing branches of the signal development. They also show the fictional dependency through successive levels. The box at the top represents the function output of the equipment and reflects the results of all of the boxes below it.

Circuit Card Locator and Function Information Plates

Circuit card locator and function information plates (troubleshooting matrices) present the maintenance information you need to isolate a specific circuit card location. The matrix for troubleshooting is on the inside of the door of each electronic cabinet assembly (ECA).

The matrix relates the ship functions to the supporting circuit card within the ECA. The ship function column lists the ship function controlled or monitored. The qualifier column identifies the specific function listed in the function column. The type column identifies the function as a control, status, or alarm function. The card location column contains the card locations within the ECA. An *X* in the card location column indicates that the circuit card is in that location in the ECA card rack. The listings in the ship function column relate to the identities of the discrete panel readouts rather than the fictional groupings. The troubleshooting matrix can be used in conjunction with the demand display directories.

TROUBLESHOOTING EQUIPMENT

The tools and test equipment needed to properly adjust, align, calibrate, and troubleshoot the ECSS equipment are listed in volume 1, chapter 6, of all the S9234-series technical manuals. This is a list of all test gear, tools, and consumables needed. However, it does not necessarily mean that all of them have to be used on each piece of equipment. Equivalent tools and test gear with superior measuring capabilities may be substituted for the items shown by a double asterisk (**) before the name.

THE ALLISON 501-K17 GTE

Maintenance and troubleshooting procedures for the Allison 501-K17 GTE are similar to the procedures used for the LM2500 engine. In all cases, you must use the proper EOSS, PMS, and technical manuals when conducting any maintenance or troubleshooting.

Volume 2 of the *Model 104/Model 139 Gas Turbine Generator Set* technical manual is divided into two parts. Part 1 contains all the necessary information, procedures, and diagrams for locating a malfunction. Part 2 contains the corrective maintenance procedures for adjustment and alignment, repair, and removal/ replacement of components.

When entering and working within the engine enclosure, follow the proper EOSS procedures and all standard safety precautions at all times.

COMPONENT CHANGEOUT

Gas turbine-powered ships are outfitted with all the equipment necessary to remove and replace engine components. As a senior petty officer, you will be supervising component changeouts. As with any job, you must plan and organize before starting the project. Since most GTE problems occur while the ship is underway, corrective maintenance must be performed immediately. If you insist upon strictly following step-by-step procedures as set forth in the technical manual, you will save time by preventing errors. Do **not** rely upon your memory for component changeouts.

PREPARATIONS

Before changing components on a GTE, be sure that the replacement parts and tools needed to do the job are available. Inspect all measuring devices (such as torque wrenches, meters, and micrometers) to ensure they are in calibration. Also be sure that you and your team have read the proper technical manual procedures.

One method that helps ensure proper use of the technical manual procedures is to provide team members with a copy of the procedures. Have them check off each step as it is completed

ESTIMATED TIME OF REPAIR

When making an estimated time of repair (ETR), you must be as accurate as possible. Your ETR could ultimately affect the operational schedule of the ship. Take into account all the factors that may affect an ETR, such as capabilities of your personnel, availability of materials, test procedures, preparations, and time for unexpected delays.

REPLACEMENT

As a supervisor, your primary concern is for the safety of your personnel and equipment. As a responsible petty officer, you set the example. Short cuts that go around safety precautions do not save time. You can prevent accidents and save time by explicitly following safety precautions and actively using safety programs such as tag-out and electrical safety.

During component changeout, keep track of tools going into and out of the GTE enclosure. Be sure your personnel use care when removing lockwires, cannon plugs, and so forth. Tag and bag all bolts, nuts, washers, and interferences that are removed for reinstallation. Capping fluid lines will prevent contamination of open systems. Use care when replacing GTE components. Most problems that arise after component replacement are easily avoided. Just remember to work carefully and always follow the procedures listed in the technical manuals.

COMPLETION OF REPAIRS

After GTE repairs are complete, ensure that the proper entries are made in the MGTESR. and Engineering Log. If the replaced component is from selected equipment, make sure you follow procedures outlined in NSTM, chapter 234, "Marine Gas Turbine Equipment Log Books and Service Records," section 8.

When preparing turn-in components for shipment, plug or cap all openings. Do not take the components apart to look inside. You may damage the component and distort the findings of the testing facilities. The repair activity must make a determination of cause of failure. Other activities collect and use information on failed components to create design improvements.

LM2500 ENGINE CHANGEOUT

At some point in your career, you may have the opportunity to supervise an engine changeout. This section discusses this topic from a supervisory standpoint. For more information on procedures for engine changeout and post changeout adjustments, you should consult the *Propulsion Gas Turbine Module LM2500,* volume 2, part 3; the Gas *Turbine Generator Set,* volume 2; and the *Team Leader Guide for FFG-7 Class Ships* or the *Team Leader Guide for DD-963 Class Ships,* as applicable.

PREPARATION

Planning a full-scale evolution such as a GTE changeout takes effort, coordination, and drive. Careful planning is an essential ingredient to your effective supervision of a GTE changeout. You can reduce delays and confusion by anticipating the needs of escorts and clearances for intermediate maintenance activities (IMAs), civilians, and other personnel involved.

An organizational meeting of all personnel, including those involved with ancillary tasks (crane operators, hook tenders, riggers, and so forth), is necessary to plan the evolution. At the meeting you should inform each individual of his or her responsibility to the overall team effort. Explain how each job affects the effort and completion schedule. You should distribute monitoring guides and inventory lists to the parties concerned with an explanation of how and when to use them. During the meeting, you should clarify the time frame established for each task completion. Having given personnel clear directions, you can expect them to perform the procedures on schedule. They should not be surprised when you arrive for a checkpoint verification. The most important topic to emphasize is safety. It is your responsibility as team leader to ensure that all safety precautions are strictly followed.

Assign a safety observer to your changeout team. His/her sole responsibility is to ensure the safety of personnel working inside the GTE module and uptakes. The safety observer should ensure ancillary personnel and technicians are qualified for tasks assigned and all safety equipment is on station before starting changeout.

COORDINATION

You can reduce or eliminate wasted of time by properly coordinating several tasks throughout the changeout. Simple things such as the proper placement of the special support equipment (SSE) containers can eliminate extra walking and moving of components. The SSE containers should be placed within the reach of the crane to avoid unnecessary movement of equipment into the lift area. Crane service must be controlled and used exclusively for the changeout. The engine containers should be brought to the site as soon as possible so they can be opened and ready for installation when scheduled.

Team members must coordinate amongst themselves for certain functions, such as the removal and installation of components and the constant passing of fixtures down and into the module. Communication between team members during the changeout process is very important. One way you can enhance both teamwork and communications is by the use of portable radio equipment.

POST CHANGEOUT REQUIREMENTS

With the completion of an engine changeout, you must return the SSE and container to the cognizant repair (support) facility. The damaged engine is packaged in a container and is then shipped to the appropriate NADEP for repairs. The paper work involved in the changeout is lengthy, but necessary for proper documentation. careful preparation of SSE containers and engine containers will ensure they will reach their final destination with no shipping damage.

Returning Containers

Returning the replaced gas generator, power turbine," and containers requires that the major components plus the $T_{5.4}$ and $P_{t5.4}$ harnesses and the speed sensors of that engine be packed within the containers. The completed log book is also returned with the container. After everything is secured within the containers and the desiccant bags have been dried out/changed, the cover is bolted down and pressurized with nitrogen for shipment. The ship's supply department is responsible for shipping the engine containers to the designated NADEP.

When the SSE containers have been completely inventoried, restacked, and secured, the supply system is responsible for returning the empty containers to their place of origin. The 05X32 office of NAVSEA is notified of the condition of the containers by the team leader via the chain of command.

Reports

Reports from the team leader require the completion of the record log book for each component and the proper closeout of that log before stowage in the engine containers. All entries should be complete up to the time of changeout, checked for correctness, and signed off by the engineer officer. The SSE containers that were inventoried on arrival are to be inventoried again at completion for reissue to the next user. The engineer officer and main propulsion assistant are required by squadron directives to notify the proper people of any irregularities at the completion of the changeout. If lessons were learned because of the changeout, notify the people concerned. Any unique or suspect occurrences could be very valuable sources of information.

LESSONS LEARNED

The following section describes some lessons learned during engine changeouts.

Pierside Changeouts

Since the first changeout on the SPRUANCE class ships, problem areas and past discrepancies during pierside changeouts have been numerous. Problems such as location of the equipment and containers at pierside can delay the job. When equipment or containers are placed out of the crane's reach, the delay is costly and frustrating.

Some changeouts have been hampered by crane service that was not totally dedicated to the job of engine changeout. Many hours were lost awaiting the crane. Crane services are needed full time throughout the changeout. All concerned personnel should realize that to complete the changeout on time, the crane and operator's services are required the full 36 hours. Engine lifting is not all that is required of the crane. Every component of the rail system plus all the lift fixtures require crane services. The crane will be in constant use, especially when the personnel basket is used. Personnel are also required to check the engine's guide rollers in the permanently mounted guide tracks for freedom of movement.

At times, inclement weather has caused difficulties. This is especially true in an unprotected harbor where the water roughness or groundswells have had an effect on the movement of the ship at the pier. Therefore, to facilitate the changeout, the ship must be pierside and should be inboard of any other ship(s) present. Sometimes, floating cranes have been used, but the evolution was still hampered by the elements.

Tenderside Changeouts

Tenderside changeouts have problems of a different nature. The tender is a stationary platform. The ship must be moved and positioned around the tender to help the crane service. The SSE containers, when stored on the tender and within reach of the crane, were on the 03 or 04 level. This made travel to and from the containers very difficult.

Horizontal Rail Systems

The horizontal rail systems also have had problems. Some of these problems are attributed to a lack of inspection before use.

— To ensure safe and proper handling of the engine and/or components by the crane operator, have the ship ballasted to remove any listing.

—Dry trunnion bearings on rail stanchions are difficult to turn. This is especially true if the adjustment ring holes have been elongated. Therefore, a grease lubricant (MLG-G-10924 or equivalent) should be used to lubricate the adjustment ring.

—The horizontal rail flanges, when not properly lined up, will make the gas generator separation hazardous. Misaligned rail flanges may cause the gas generator position to shift and possibly damage the C-sump air seals. On mating up gas generator to power turbine, the No. 6 bearing cage can be damaged when the front-frame lift fixture roller crosses the forward flange in the rail. This makes the gas generator shift weight.

—The adjustable rollers on the lift fixtures are susceptible to corrosion. Corrosion may cause the roller to jam into one position. If not properly lubricated before use, the adjustable rollers on the lift fixtures are capable of freezing up. This makes it impossible to center the engine.

—When not properly serviced and filled with cylinder oil, the hydraulic support mechanism for the compressor front frame will not permit the jack to be extended far enough to support the front frame for removal of the support pins.

—Ensure all feeder rail sections are installed and aligned before checking the travel of the system with a hand-held roller.

—If a bearing failure necessitates an engine changeout, a complete flushing of the lube oil system is required.

Tag and Bagging Practices

There is evidence that tagging and bagging practices on engine changeouts have not been followed to the letter. This costs time during reassembly. Proper identification is a valuable asset when the new engine is reassembled in place. Lost and broken bolts, in some cases, do not exist as onboard spares. Therefore, you need to exercise care in disassembling and handling. Once bags have been filled and identified, place them in a secure place until they are required for the reassembly.

Replacement Engines

Replacement engines, when received, may not be complete with all the fittings and adapters necessary for connection. In some cases, a replaced engine was in the container and heading for the supply depot before this discovery was made. This caused additional time to be wasted reopening the container and resealing it after the parts or items were removed. Time has also been lost when the replacement engine's turbine midframe flange was improperly clocked and another engine had to be brought to the changeout site.

Silencers

Mark the location of the silencer hold-down brackets before removal. Proper marking makes it much easier to reinstall the brackets and silencers.

Quality Assurance

Review QA requirements of *Combined Forces Afloat Quality Assurance Manual,* COMNAVSURFLANTINST 5090.1A and COMNAVSURFPACINST 4855.22, for level A repairs.

GTG ENGINE CHANGEOUT

GTG engine changeout procedures are described in detail in the technical manuals, *Model 104 Gas Turbine Generator Set,* volume 2, and *Model 139 Gas Turbine*

Generator Set, volume 2. These procedures provide detailed engine and interference removal instructions. These instructions should be strictly followed due to the vast differences in removal procedures between a propulsion GTE and an SSGTG.

You must use the same planning skills and engineering practices in a GTG engine changeout as you use in an LM2500 GTE changeout. The same strict application of safety precautions and following of technical manual procedures apply to every GTG engine changeout.

COOPERATION

Ship's readiness is the common purpose in the changeout evolution. All personnel involved should share a common commitment in achieving that purpose. A willingness by each individual to submerge his or her personal interest in favor of getting the job done is a necessary prerequisite to cooperation. You may have to adjust working hours and watch-standing duties to meet changeout schedule requirements. Personnel may be assigned to duties they do not want to perform. Emphasize each individual's importance, willingness, and contribution to the evolution. Engine changeout is an opportunist y to display your professional abilities as a leader and technician

MAINTENANCE TIPS

As a GS supervisor you will be responsible for the proper completion of most maintenance procedures. This section will cover some maintenance tips that can help you to understand the critical relationship between maintenance performance and the proper operation of the LM2500. Remember, the contents of this section are **FOR TRAINING PURPOSES ONLY** and should in no way replace the use of the PMS or the manufacturer's maintenance procedures.

PLA RIGGING

If the PLA is replaced for whatever cause, the PLA rig check (mechanical and electrical) must be accomplished. If the main fuel control (MFC) rig pin does not fit properly (too loose, too tight, or can't be fully inserted), re-rig the PLA. Always comply with the PLA electrical rig check after you are assured that the throttle command voltages are properly set (idle and full throttle).

Mechanical

The key to a successful mechanical rigging is a proper alignment. Remember, although the PLA actuator arm is mechanically linked to the MFC lever arm, the PLA is electrically driven. The slightest mechanical restriction (binding) may cause incorrect PLA movement during engine operation. PLA movement is most sensitive to a restriction when in either engine speed or torque, and/or shaft torque limiting condition. If a possible restriction is suspected, advance and retard the PLA electrically and check for any hesitation or jerking during travel. If hesitation exists, there may be a mechanical restriction.

Electrical

The normal process for this rigging will be checking dc voltages at idle and full throttle positions. However, the moment the throttle is moved out of idle, indicated torque will go to midrange and oscillate. For example, on the DD-963/DDG-993 class ships, if mid-torque oscillations are accompanied by an overtorque indication and a PLA failure indication, then another problem exists.

Why? When the PLA is at idle, there is a $PT_{5.4}$ bias that assures $PT_{5.4}$ is greater than PT_2 for engine start purposes. During PLA electrical rigging, the bias drops out when the throttle is advanced.

If $PT_{5.4}$ is several tenths of a pound less than PT_2, the torque computer goes berserk. But, PLA rigging may be continued by pressing the BATTLE OVERRIDE button.

However, suppose you have just been informed that the $PT_{5.4}$ transducer requires calibration When the torque goes berserk as described, immediately dial up $PT_{5.4}$ and PT_2 on the respective DDIs. $PT_{5.4}$ will be lower than PT_2, thus requiring the activation of BATTLE OVERRIDE to continue. This lower reading tells you the $PT_{5.4}$ transducer requires calibration.

VSV FEEDBACK CABLE RIGGING

Why is it accomplished? Why is it important?

VSV feedback cable rigging is necessary because we are "timing" a pilot valve inside the MFC so the correct vane angle is obtained for a given CIT/gas generator speed day. Actually, we are assuring that the pilot valve is timed to close off high pressure fuel flow to both the ROD END and the HEAD END pressure ports inside the MFC. These pressure ports direct the fuel flow to the vane actuators via tubing.

This timing is accomplished by pumping the vanes to the full open position and maintaining 100 to 200 psig on the system. At the same time, be sure you check to see if the bottom of the rig plates are parallel with each other. NEVER relax the pressure on the system while performing the rig plate check. If the pressure is relaxed, the feedback lever may drift and the rig will be incorrect.

When the system is full open, and 100 psig is applied, try to move the bolt back and forth on the forward end of the cable at the bellcrank. If the bolt cannot be moved, it most likely indicates a binding at the front section of the cable assembly. Of course, this "assumes" that the bolt is of the correct diameter and is normally free to move. If the bolt cannot be moved back and forth, reverse the pump selector handle to the RE (rod end) position. You then need to apply a few strokes to move the vanes slightly towards the closed position. If the bolt becomes free to move, the forward section of the cable assembly is definitely binding. Binding is easily connected by loosening the jamnut on the forward rod end bearing and rotating the rod end bearing a half turn at a time. This adjustment shortens the distance (right-hand rotation) and usually solves the problem. Reinstall and recheck the rigging. If the rigging is still slightly off, use the trimmer bracket adjustment to make the correction.

The bottom line

What are you really trying to accomplish? Look at it this way. The system is pumped full open, and the piston inside each actuator is physically bottomed out. This in turn fixes the position of the bellcrank bolt hole when a minimum of 100 psig is maintained. If you manually hold the feedback lever arm in order to match the bottom of the rig plates, the plates become parallel to each other. The two fixed ends now have a fixed distance between them. By adjusting the length of the cable assembly, you will maintain a proper fit between the two fixed points.

You have now successfully accomplished a VSV feedback cable rigging. You were able to do so by a combination of adjusting the fore and aft rod end bearings within the limitations and following the published trimmer bracket instructions.

VSV SCHEDULING

VSV scheduling is verified by using the variable vane protractor (1C5714). You must check the protractor for accuracy before every use on the engine. The check will detect any inaccuracies due to damage, wear, and so forth. Use the protractor setmaster (9441M67G01) to accomplish this test. The protractor is installed on the master vane located at the 9 o'clock split line, aft looking forward.

CAUTION

Do not check the vane angle if idle speed is less than 4,900 rpm, or greater than 5,000 rpm. Before adjusting the idle rpm screw on the MFC, assure PLA mechanical and electrical rigging is connect.

Once the protractor's accuracy has been verified, you are now ready to install the protractor on the engine. Install the protractor locator on the engine and ensure it mounts correctly (it will only goon one way correctly).

If installed incorrectly, the shaft cannot be threaded on the vane stud. If the locator is wiggled around so that the shaft can be threaded on the vane stud, it will be cocked, but the protractor can still be installed over the locator. However, the vane angle is now 4° too far open.

If the protractor is left in this position, the angle will be 4° more open when checked at idle rpm than when compared to the table. This means a perfectly serviceable engine could be rejected because it failed the angle check. When installed correctly, the locator is flush to the lever and, at the same time, the shaft can be threaded on the vane stud without wiggling it around.

GAS TURBINE PRESERVATION AND CORROSION CONTROL

Modern gas turbines and their support equipment are dependent upon the structural soundness of the metals from which they are fabricated. The greatest threat to the structural integrity of this equipment is metal corrosion. With the higher demands being made on these metals, both in strength and in closer tolerances, this equipment would rapidly deteriorate and become inoperative without regular attention to corrosion control.

Corrosion endangers the gas turbine and its support equipment by reducing the strength and changing the structural characteristics of the materials used in their construction. All such materials are designed to carry certain loads and withstand given stresses and temperatures, as well as to provide an extra margin of strength for safety. Corrosion can weaken the structure, thereby reducing or eliminating this safety factor. Replacement or repair operations are costly, time consuming, and restrict the usage of the equipment. Corrosion in electronic and electrical components can cause serious malfunctions. These malfunctions reduce the effectiveness and reliability of the engineering plant and can often completely destroy these components.

A thorough comprehension of the dangers of corrosion and the ability to recognize and cope with the various types of corrosion should be included in the objectives of any maintenance training program. As a work center supervisor, you may find that corrosion prevention and control frequently turn out to be an all-hands evolution. To some extent you can avoid this situation through frequent inspections, effective use of available manpower, and proper training of your subordinates.

CORROSION

The problem of gas turbine engines and support equipment protection is threefold: (1) prevention of corrosion of the metal parts; (2) control of deterioration of nonmetallic materials; and (3) elimination of physical damage during replacement, repair, and maintenance. Of the three basic problems, corrosion of metals is the most difficult to control.

Metal corrosion is the deterioration of a metal. When the metal is combined with oxygen, it forms metallic oxides. This combining is a chemical process that is essentially the reverse of the process of smelting metal from ore. Very few metals occur in nature in the pure state. For the most part, they occur as metallic oxides. The refining process involves the extraction of relatively pure metal from its ore and the addition of other elements (both metallic and nonmetallic) to form alloys.

After refining, regardless of whether or not they are alloyed, base metals possess a potential or tendency to return to their natural state. However, this potential is not enough in itself to initiate and promote this reversion. There must also exist a corrosive environment in which the significant element is oxygen. It is the process of oxidation that causes metals to corrode.

It is a well-known fact that the tendency to corrode varies widely between various metals. For example, magnesium alloys are very difficult to protect and have a very low corrosion resistance. Copper alloys have relatively good corrosion resistance and are very easy to protect.

Corrosion may take place over the entire surface of a metal by having a chemical reaction with the surrounding environment. Or corrosion may be electrochemical in nature between two different metallic materials or two points on the surface of the same alloy that differ in chemical activity. The presence of some type of moisture is usually essential for corrosion to exist.

CAUSES

Prevention and control of corrosion begins with an understanding of the causes and nature of this phenomenon. As stated earlier, corrosion is caused by an electrochemical or a direct chemical reaction of a metal with other elements. In the direct chemical attack, the reaction is similar to that which occurs when acid is applied to bare metal. Corrosion in its most familiar form is a reaction between metal and water and is electrochemical in nature.

In an electrochemical attack, metals of different electrical potential are involved and they need not be in direct contact. When one metal contains positively charged ions and the other metal contains negatively charged ions and an electrical conductor is bridged between them, current will flow as in the discharge of a dry-cell battery. In this type of reaction, the conductor bridge may be any foreign material such as water, dirt, grease, or any debris that is capable of acting as an electrolyte. The presence of salt in any of the foregoing media tends to accelerate the current flow and hence speed the rate of corrosive attack.

Once the electrolyte has completed the circuit (fig. 2-32), the electron flow is established within the metal in the direction of the negatively charged area (cathode). The positively charged area (anode) is eventually destroyed. All preventive measures taken with respect to corrosion prevention and control are designed primarily to avoid the establishment of an electrical circuit. Or secondly, to remove electron flow as soon as possible after its establishment before serious damage can result.

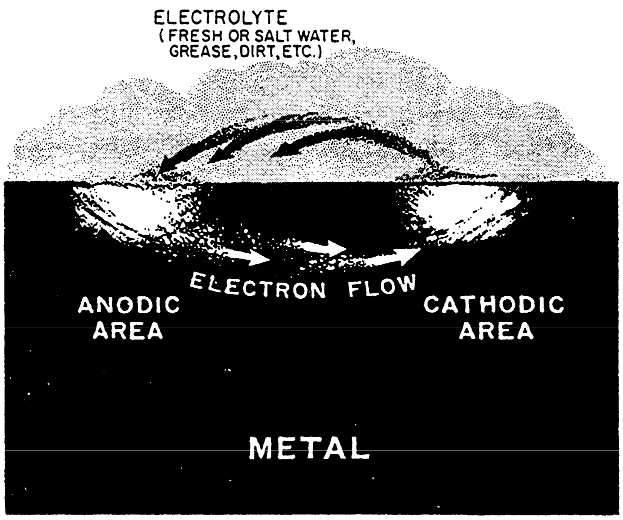


Figure 2-32.—Simplified corrosion cell.

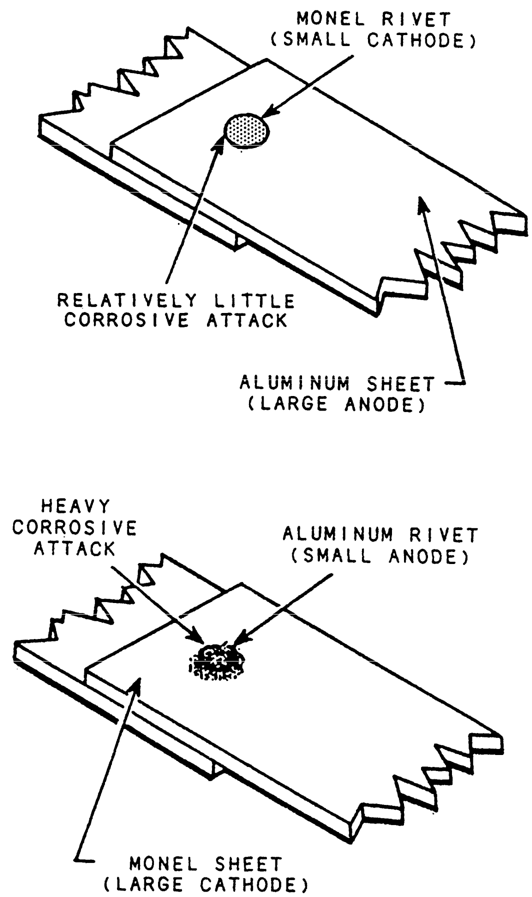
Electrochemical attack is evidenced in several forms depending on the metal involved, its size and shape, its specific function, the atmospheric conditions, and the type of corrosion-producing agent (electrolyte) present. A great deal is known about the many forms of metal deterioration that result from electrochemical attack. But despite extensive research and experimentation, there is still much to be learned about other more complex and subtle forms of metal deterioration. Descriptions are provided later in this chapter for the more common forms of corrosion.

Since there are so many contributing factors to the process of corrosion, selection of materials by the manufacturer must be made with weight versus strength as a primary consideration and corrosion properties as a secondary consideration. However, close attention during design and production is given to heat treating and annealing procedures, protective coatings, choice and application of moisture barrier materials, dissimilar metal contacts and accesses. Every logical precaution is taken by the manufacturers to inhibit the onset and spread of corrosive attacks.

There are many factors that affect the type, speed, cause, and seriousness of metal corrosion. Some of these factors can be controlled; others cannot. Preventive maintenance such as inspection, cleaning, painting, and preservation are within the control of maintenance personnel. Preventive maintenance offers the most positive means of corrosion deterrence.

The electrochemical reaction that causes metal to corrode is a much more serious factor under wet, humid conditions. The salt in seawater and in the air is the greatest single cause of corrosion. Hot environments speed the corrosion process because the electrochemical reaction develops faster in a warm solution. Warm moist air is usually sufficient to start corrosion if the metal surfaces are unprotected.

Another corrosion factor is the relationship between dissimilar metals. When two dissimilar metals come in contact, if the more active metal is smaller than the less active one, corrosive attack will be severe and extensive. Insulation between such contact will inhibit this process. If the area of the less active metal is small compared to the other metal, corrosive attack will be relatively slight (fig. 2-33).



A. Compressor Blade Nomenclature
B. Liner Band Numbering
C. Combustor Assembly Nomenclature
D. HP Turbine Nozzle Nomenclature
E. HP Turbine Rotor Blade Nomenclature
F. Power Turbine Nozzle Nomenclature
G. Power Turbine Rotor Blade

Figure 2-33.—Effects of area relationships in dissimilar metal contacts.

CHARACTERISTICS

The appearance of corrosion will vary with the metal involved. The following discussion includes brief descriptions of typical corrosion product characteristics. These descriptions are only for the most common materials used in gas turbine propulsion and support equipment.

Iron and Steel

Possibly the best known and most easily recognized of all forms of metal corrosion is the familiar reddish-colored iron rust. When iron and its alloys corrode, dark iron oxide coatings usually form first. These coatings, such as heat scale on steel sheet stock and the magnetite layer that forms on the inside of boiler tubes, protect iron surfaces rather efficiently. However, if sufficient oxygen and moisture are present, the iron oxide is soon converted to hydrated ferric oxide, which is conventional red rust. Hydrated ferric oxide, red rust, does not protect surfaces. It destroys surfaces.

Aluminum

Aluminum and its alloys exhibit a wide range of corrosive attacks, varying from general etching of surfaces to penetrating attacks along the internal grain boundaries of the metal. The corrosion products of aluminum are seen as white-gray powdery deposits.

Copper and Copper Alloys

Copper and its alloys are generally corrosion resistant, although the products of corrosive attack on copper are commonly known. Sometimes copper or copper alloy surfaces will tarnish to a gray-green color, while the surface will remain relatively smooth. This discoloration is the result of the formation of a fine-grained, airtight copper oxide crust, called a patina.

Patina offers good protection for the underlying metal in ordinary situations. However, exposure of copper alloys to moisture or salt spray will cause the formation of blue or green salts called verdigris. The presence of verdigris indicates active corrosion.

Cadmium and Zinc

Cadmium is used as a coating to protect the area to which it is applied and to provide a compatible surface when the part is in contact with other metals. The cadmium plate supplies sacrificial protection to the underlying metal because of its great activity. During the time it is protecting the base metal, the cadmium is intentionally being consumed. Zinc coatings are used for the same purpose, although to a lesser extent. Attack is evident by white-to-brown-to-black mottling of the surfaces. These indications do NOT indicate deterioration of the base metal. Until the characteristic colors peculiar to corrosion of the base metal appear, the coating is still performing its protective function.

Nickel and Chromium Alloys

Nickel and chromium alloys are also used as protective agents. They are used as electroplated coatings and as alloying constituents with iron in stainless steels and with other metals such as copper. Nickel and chromium plate provide protection by the formation of an actual physical noncorrosive barrier over the steel. Electroplated coatings, particularly chromium on steel, are somewhat porous. Eventually, corrosion starts at these pores unless a supplementary coating is applied and maintained.

TYPES OF CORROSION

As stated previously, corrosion may occur in several forms, depending upon the metal involved, its size and shape, its specific function, the atmospheric conditions, and the corrosion-producing agents present. Those corrosion types described in this section are the most common forms found on gas turbine engines and machinery structures.

Direct Surface Attack

The surface effect produced by reaction of the metal surface to oxygen in the air is a uniform etching of the metal. The rusting of steel, tarnishing of copper alloys, and the general dulling of aluminum surfaces are common examples of direct surface attacks. If such corrosion is allowed to continue unabated, the surface becomes rough, and in the case of aluminum, frosty in appearance. Direct surface attack is sometimes referred to as uniform etch corrosion.

Galvanic Corrosion

Galvanic corrosion is the term applied to the accelerated corrosion of metal caused by dissimilar metals being in contact in a corrosive medium.

Dissimilar metal corrosion is usually a result of faulty design or improper maintenance practices which result in dissimilar metals coming in contact with each other. This is usually seen as a buildup of corrosion at the joint between the metals. For example, when aluminum pieces are attached with steel bolts and moisture or contamination are present, galvanic corrosion occurs around the fasteners.

Pitting

The most common effect of corrosion on aluminum alloys is pitting. It is caused primarily by variations in the grain structure between adjacent areas on the metal surfaces that are in contact with a corrosive environment. Pitting is first noticeable as a white or gray powdery deposit, similar to dust, that blotches the surface. When the superficial deposit is cleaned away, tiny pits or holes can be seen in the surface. These pits may appear either as relatively shallow indentations or as deeper cavities of small diameters. Pitting may occur in any metal, but it is particularly characteristic of aluminum and aluminum alloys.

Intergranular Corrosion

Intergranular corrosion is an attack on the grain boundaries of some alloys under specific renditions. During heat treatment, these alloys are heated to a temperature that dissolves the alloying elements. As the metal cools, these elements combine to form other compounds. If the cooling rate is slow, they form predominantly at the grain boundaries. These compounds differ electrochemically from the metal adjacent to the grain boundaries. These altered compounds can be either anodic or cathodic to the adjoining areas, depending on their composition. The presence of an electrolyte will result in an attack on the anodic area. This attack will generally be quite rapid and can exist without visible evidence.

As the corrosion advances, it reveals itself by lifting up the surface grain of the metal by the force of expanding corrosion products occurring at the grain boundaries just below the surface. This advanced attack is referred to as EXFOLIATION. Recognition and necessary corrective action to immediately correct such serious instances of corrosion are vital. This type of attack can seriously weaken structural members before the volume of corrosion products accumulate on the surface and the damage becomes apparent.

Fretting

Fretting is a limited but highly damaging type of corrosion caused by a slight vibration, friction, or slippage between two contacting surfaces that are under stress and heavily loaded. Fretting is usually associated with machined parts such as the contact area of bearing surfaces, two mating surfaces, and bolted assemblies. At least one of the surfaces must be metal.

In fretting, the slipping movement at the interface of the contacting surface destroys the continuity of the protective films that may be present on the surfaces. This action removes fine particles of the basic metal. The particles oxidize and form abrasive materials that further accumulate and agitate within a confined area to produce deep pits. Such pits are usually located where they can increase the fatigue potential of the metal.

Fretting is evidenced at an early stage by surface discoloration and by the presence of corrosion products in any lubrication. Lubricating and securing the parts so that they are rigid are the most effective measures for the prevention of this type of corrosion.

Stress

Stress, evidenced by cracking, is caused by the simultaneous effects of tensile stress and corrosion. Stress may be internal or applied.

Internal stresses are produced by nonuniform deformation during cold working conditions, by unequal cooling from high temperatures during heat treatment, and by internal-structural rearrangement involving volume changes. Stresses set up when a piece is deformed. Examples of internal stresses include those induced by press-and-shrink fits and those in rivets and bolts.

Concealed stress is a more dangerous condition than design stress. Concealed stress corrosion is difficult to recognize before it has overcome the design safety factor. The magnitude of the stress varies from point-to-point within the metal. Stresses in the neighborhood of the yield strength are generally necessary to promote stress corrosion cracking, but failures may occur at lower stresses.

Fatigue

Fatigue is a special type of stress corrosion. It is caused by the combined effects of corrosion and stresses applied in cycles. An example of cyclic stress fatigue is the alternating loads to which the connecting rod of a double-acting piston in an air compressor is subjected. During the extension (up) stroke a compression load is applied, and during the retraction (down) stroke a tensile or stretching load is applied. Fatigue damage is greater than the combined damage of corrosion and stresses. Fracture of a metal part due to fatigue corrosion generally occurs at a stress far below the fatigue limit in a laboratory environment, even though the amount of corrosion is very small. For this reason, protection of all parts subject to alternating stress is particularly important wherever practical, even in environments that are only mildly corrosive.

PREVENTION AND CONTROL

Much has been done over the years to improve the corrosion resistance of newer Navy warships. Improvements include the selection and combination of materials of construction, chemical surface treatments, insulation of dissimilar metals, and protective paint finishes. All these improvements are aimed at reducing maintenance as well as improving reliability. Despite refinements in design and construction, corrosion control is a problem that requires a continuous maintenance program.

With this idea in mind, the NAVSEASYSCOM has developed some excellent ship class corrosion control manuals for you to use as reference tools aboard ship. There are two manuals a GS supervisor should read. They are the *Corrosion Control and Prevention Manual* for DD-963 class ships, NAVSEA S9630-AB-MAN-010, and the *Standard Corrosion Control Manual,* NAVSEA S9630-AE-MAN-010.

Cleaning

As a leading petty officer or work center supervisor, one of your most important aids in the prevention and control of corrosion is an adequate cleaning program. The term *clean* means to do the best job possible using the time, materials, and personnel available. A daily wipedown of all machinery is better than no cleaning at all. The importance of frequent cleaning cannot be overemphasized. Any cleaning procedures, however, should be in the mildest form possible to produce the desired results. For example, spraying water around multipin connectors can cause electrical shorts or grounds, with a possible loss of control functions or equipment damage.

In general, gas turbine engines and enclosures should be cleaned as often as necessary to keep surfaces free of salt, dirt, oil, and other corrosive deposits. A thorough inspection and cleaning of gas turbine intakes and enclosures should always be done in conformance with PMS requirements. These cleanings and inspections should be done before getting underway, after an extended stay in port, and after returning to port from an extended time at sea.

Since marine gas turbines are more subject to internal corrosion than engines used in other types of applications, internal cleaning is of particular importance. This is accomplished by means of water washing. A mixture of B & B 3100 water-wash compound and distilled water is injected into the engine air inlet while it is being motored and then rinsed with distilled water in the same manner. It is then operated for about 5 minutes to remove all liquid. For more detailed information on this procedure, consult the applicable PMS card.

Characteristics of Metals

As a GS supervisor, you should have a thorough knowledge of the characteristics of the various metals used throughout the engineering plant, as well as the engines themselves.

To some extent, all metals are subject to corrosion To keep corrosion to a minimum, corrosion-resistant metals are used to the fullest extent possible consistent with weight, strength, and cost considerations. On exposed surfaces, the major preventive for providing relative freedom from corrosion is a coating of protective surface film. This film can be in the form of an electroplate, paint, or chemicaI treatment, whichever is most practical.

Most of the metals used in the engineering plants require special preventive measures to guard against corrosion. In the case of aluminum alloys, the metal is usually anodized or chemically treated and painted. Steel and other metals such as brass or bronze (with the exception of stainless steels) use cadmium or zinc plating, protective paint, or both. In all cases, the protective finish must be maintained to keep active corrosion to an absolute minimum.

PRESERVATION AND DEPRESERVATION OF GAS TURBINE ENGINES

The main purpose of engine preservation is to prevent corrosion of the various types of materials that make up the engine and its accessories. Preservation also ensures against gumming, sticking, and corrosion of the internal passages.

Engine preservation and depreservation is vital because the corrosion of engine structures can and does have a great effect on the operational and structural integrity of the unit. Therefore, it is important that you know about methods of preservation, materials used, and depreservation procedures.

PRESERVATION AND PACKAGING FOR STORAGE

If you know that an engine is to be shipped or stored, you must make plans to preserved it prior to removal from the ship. Engines to be taken out of operation for periods of up to 1 month require only that the unit be protected from the elements. Units that will be stored or out of service for more than a month must be preserved for storage.

Packaging for storage should comply with current instructions for engine shipment furnished by the manufacturers. If specific manufacturer's instructions are not available, then the engine should be placed in a hermetically sealed metal container with a humidity control and an external humidity indicator.

All major engine parts, no matter how badly worn or damaged, must be returned with the engine whether it is to be overhauled or salvaged. Remember, the entire assembly (engine and accessories) must be protected from damage during shipment. When preparing the engine for shipment, you must be sure that all fuel lines, receptacles, oil lines, intakes, exhausts, and any other openings in the engine or its components are capped or covered before the engine is removed.

For further information, packaging requirements are given in MIL-E-17341, MIL-E-17555, and MIL-E-17289.

DEPRESERVATION

An engine that has been in storage, or inoperable for an extended period of time, must be depreserved before it can be placed in service. Before connecting the engine to the external portion of the fuel and oil system (supply tank, coolers, falters, and so forth), the external tubing and equipment must be thoroughly flushed and purged. After installation, fill the oil sump (Allison) or LOSCA (LM2500) with clean lubricating oil to the proper operating level.

CAUTION

To prevent accidental firing, ensure that the engine ignition circuit is disconnected when priming the fuel control and the fuel system.

Before initial operation, the engine fuel system must be flushed and purged. To accomplish this, the engine is motored until all bubbles are out of the fuel stream and only fuel comes through. While motoring, observe the engine oil pressure. If no pressure is indicated, the cause must be determined and corrected before the engine can be started. In all cases, the manufacturers' technical manual must be consulted for specific instructions on the depreservation and start-up of each particular engine.

SUMMARY

In this chapter we have discussed object damage, borescope inspection, and troubleshooting related to GTEs. We also discussed corrosion, its causes, effects, and some of the methods available to us to combat and minimize it. Since a TRAMAN is not designed to deal with all aspects of anyone subject, you should study the various publications on the prevention and control of corrosion mentioned in this chapter. of particular interest are the *Propulsion Gas Turbine Manual LM2500,* volume 2, part 2, S9234-AD-MMO-040 LM2500; the *NSTM,* chapter 234, "Marine Gas Turbines," S9086-HC-STM-000; and *Corrosion Control and Prevention Manual for DD-963 Class Ships,* NAVSEA S9630-AB-MAN-010. Throughout this chapter and again in the summary you have often been referred to the applicable technical manuals or the PMS for specific information. You must use these references to guide you through the procedures. Proper use of the technical manuals and the PMS will ensure that you make a complete inspection and/or properly isolate a problem.

Table 2-1a.—LM2500 Condition Codes

CONDITION OF PART	CODE	DEFINITION	RELATED TERMS
ACCEPTABLE	01	Satisfactory for further use.	OK, Checked OK
BATTERED	02	Damaged by repeated blows or impacts.	
BENT	03	Sharp deviation from original line or plane, usually caused by lateral force. Example: Creased or folded sheet metal.	Creased, Folded, Kinked
BINDING	04	Restricted movement such as tightening or sticking condition, resulting from high or low temperature, foreign object jammed in mechanism, etc.	Sticking, Tight
BOWED	05	Curved or gradual deviation from original line or plane usually caused by lateral force and/or heat.	
BROKEN	06	Separated by force into two or more pieces. (Complete destruction of cohesion.)	Fractured
BULGED	07	Localized outward or inward swelling, usually caused by excessive local heating and/or differential pressure.	Ballooned, Swelling
BURNED	08	Destructive oxidation, usually caused by higher temperature than the parent material can withstand.	
BURRED	09	A rough edge or a sharp projection on the edge of the surface of the parent material.	
CARBONED	10	Accumulation of carbon deposits.	Carbon Covered, Carbon Tracked, Coked
CHAFING	11	A rubbed action between parts having limited relative motion (as in vibration).	Abrasion, Fretting
CHECKED	12	Surface cracks, usually caused by heat.	
CHIPPED	13	A breaking away of the edge, corner, or surface of the parent material, usually caused by heavy impact (not flaking).	
CORRODED	14	Gradual destruction of the parent material by chemical action. Often evidenced by oxide buildup on the surface of the parent material.	Rusted, Oxidation
CRACKED	15	Visible partial separation of material which may progress to a complete break.	
CURLED	16	A condition where the tip(s) of compressor blades or turbine blades have been curled over due to rubbing against the engine casings.	
DENTED	17	A surface indentation with rounded bottom, usually caused by impact of a foreign object. Parent material is displaced, seldom separated.	Peened
DEPOSITS	18	A buildup of material on a part either from foreign material or from another part not in direct contact.	

PAGE 1

Table 2-1b.—LM2500 Condition Codes (Cont'd)

CONDITION OF PART	CODE	DEFINITION	RELATED TERMS
DISTORTED	19	Extensive deformation of the original contour of a part, usually due to impact of a foreign object, structural stresses, excessive localized heating, or any combination of these.	Buckled, Deformed, Depressed, Twisted, Warped
ERODED	20	Carry away of material by flow of fluids or gases, accelerated by applied pressure.	
FLAKE	21	A thin chiplike or scalelike layer of metal.	
FRETTING	22	Wear in a rippled pattern, caused by friction.	Chafing, Abrasion
FROSTED	23	A dulled, roughened surface finish.	
FUSED	24	Joining together of two materials, usually caused by heat or friction.	
GALL	25	A defect caused by the movement of two surfaces in contact with each other. In most cases an accumulation of foreign material is deposited on the parent material.	See Pickup
GOUGED	26	Scooping out of material, usually caused by a foreign object.	Furrowed
GROOVED	27	Smooth, rounded furrow or furrows of wear, usually wider than scoring with rounded corners and smooth on the groove bottom. Example: A ball bearing wearing into a ring could cause a grooved condition.	
INDICATIONS	28	Cracks, inclusions, fractures, etc., not visible without fluorescent or magnetic penetrants.	
KNIFING	29	Erosion resulting in sharp edges.	
LOOSE	30	Separation of the part from another part to which it is normally affixed.	Separated, Disengaged
MELTED	31	Deformation from original configuration due to heat, friction, or pressure as with melted bearings or insulation.	
MISMATCHED	32	Improper association of two or more parts.	
MISPOSITIONED	33	Improper installation of a part, resulting in damage to the installed part or to associated parts.	Misaligned, Reversed
NICKED	34	A sharp surface indentation caused by impact of a foreign object. Parent material is displaced, seldom separated.	
OBSTRUCTED	35	Prevention of free flow of a fluid (air, oil, fuel, water) because of foreign material in the flow path or malfunction in the flow member.	Clogged, Contaminated, Plugged, Restricted
OVER-TEMPERATURE	36	Subjected to excessive temperature, usually evidenced by change in color and appearance of the part.	Heat Discolored

PAGE 2

Table 2-1c.—LM2500 Condition Codes (Cont'd)

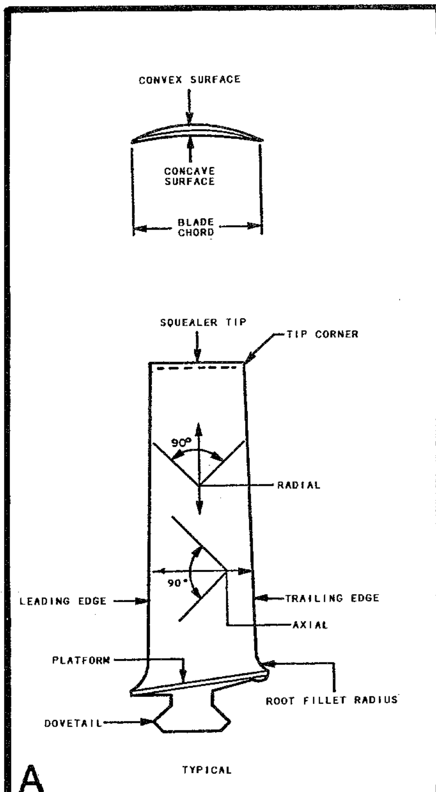
CONDITION OF PART	CODE	DEFINITION	RELATED TERMS
OXIDATION	37	A surface deterioration by the chemical reaction between oxygen in the air and the metal surface. Attack is manifested as red rust in iron and low-alloy steels when formed at ambient temperature. The oxides which form on super alloys are complex and can be green or black, depending on material composition and temperature at which it is formed.	
PART MISSING	38	The absence of a required part.	Loss
PEELED	39	A breaking away of surface finish such as coating, plating, etc.; peeling would be flaking or large pieces. A blistered condition usually precedes or accompanies flaking.	Blistered, Flaked
PICKUP	40	Transfer of one material into or upon the surface of another, caused by contact between moving parts or deposits of molten material on a cooler material.	Burr (usually tool-rub leaving high parent material), Gall, High Spot, Imbedment, Inclusion (usually Pileup), Protrusion (deposit on parent material), Metalization
PINCHED	41	Distortion of one or more surfaces of the parent material, caused by pressure.	Bound, Compressed, Flattened, Seized (see Seizure), Smashed (without separation into pieces), Squashed, Squeezed, Tight
PITTED	42	Small irregular shaped cavities in the surface of the parent material, usually caused by corrosion, chipping, or heavy electrical discharge.	
ROLLED-OVER	43	Lipping or rounding of metal edge.	Lipped, Turned Metal
RUBBED	44	To move with pressure or friction against another part, such as compressor rub.	
SCUFF	45	A surface roughened by wear.	Scape, Scratch
SEIZURE	46	A welding or binding of two surfaces which prevents further movement.	Bound Up, Frozen, Tight, (see Pinched), Tight (fit), Wedged, Welded (without external assistance)
SCORED	47	Deep scratch or scratches made on the part surface by sharp edges of foreign particles.	
SCRATCHED	48	Light, narrow, shallow mark or marks caused by movement of a sharp object or particle across a surface. Material is displaced, not removed.	

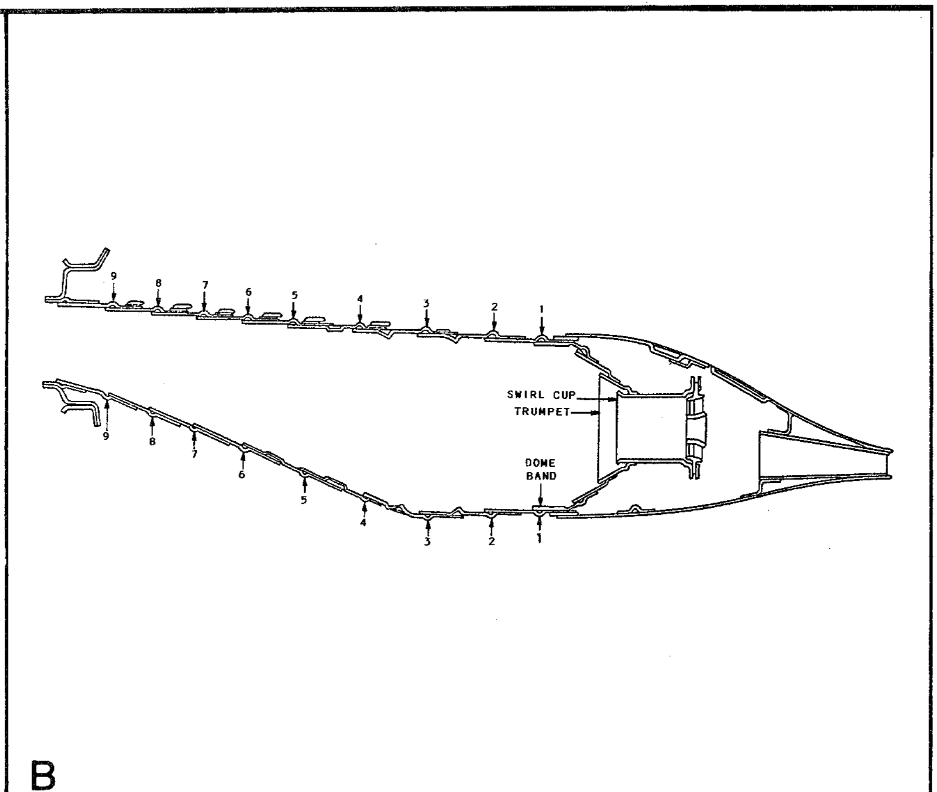
PAGE 3

Table 2-1d.—LM2500 Condition Codes (Cont'd)

CONDITION OF PART	CODE	DEFINITION	RELATED TERMS
SHEARED	49	Dividing a body by cutting action; i.e., division of a body so as to cause its parts to slide relative to each other in a direction parallel to their plane of contact.	
SHINGLING	50	The effect of two adjacent surfaces overlapping, usually caused by wear to one edge of the adjoining planes.	
SPALL	51	Broken or crushed material due to heat, mechanical, or structural causes. Chipping off of small fragments under the action of abrasion.	Chip
STALL	52	A disruption of normally smooth airflow through the gas turbine. The compressor blades stall in much the same manner as the wings of an aircraft. A high-speed stall is indicated by a rise of $T_{5.4}$ with corresponding reductions of N_1 and P_{s3}. A sub-idle stall is indicated by a rapid rise in $T_{5.4}$ and hangup of N_1. Personnel in the immediate area of the base enclosure may hear a chugging or a rumble during a stall. Stalls may occur during gas turbine acceleration, deceleration, or steady opertion. Stalls generally are the result of foreign object ingestion, an improperly rigged or malfunctioning compressor VSV feedback system, a malfunctioning CIT sensor, or main fuel control. The preceeding information is intentionally brief to provide a basis of understanding for the term *Stall*.	
SULFIDATION	53	A form of hot corrosion in heat-resistant alloys by the reaction at the metal surface of sodium chloride (sea air) and sulfur (from the fuel). Attack usually occurs over a broad front and can be identified as gray or black blisters (early stage) or surface delamination (advanced stages).	
TIP CLANG	54	The banging together of the leading edge of one blade and the trailing edge of the adjacent blade during stall. Tip clang results in tiraling edge fretting that can best be discovered on stages 3 through 6.	
TORN	55	Separation by pulling apart.	
VARNISH FILM	56	A hard surface film on metal, strawcolor to very dark brown, buildup by exposure to dry chemicals or fluids (commonly oil) while the part is heated above the breakdown point of the chemical or fluid.	Banded, Discolored, Oxidized, Stained
WARPED	57	Not true in plane or in line; out of true shape.	Distorted, Bent, Twisted, Buckled, Contorted
WORN EXCESSIVELY	58	Material of part consumed as a result of exposure to operation or usage.	

PAGE 4





<u>LEGEND</u>

A. COMPRESSOR BLADE NOMENCLATURE

B. LINER BAND NUMBERING

C. COMBUSTOR ASSEMBLY NOMENCLATURE

D. HP TURBINE NOZZLE NOMENCLATURE

E. HP TURBINE ROTOR BLADE NOMENCLATURE

F. POWER TURBINE NOZZLE NOMENCLATURE

G. POWER TURBINE ROTOR BLADE

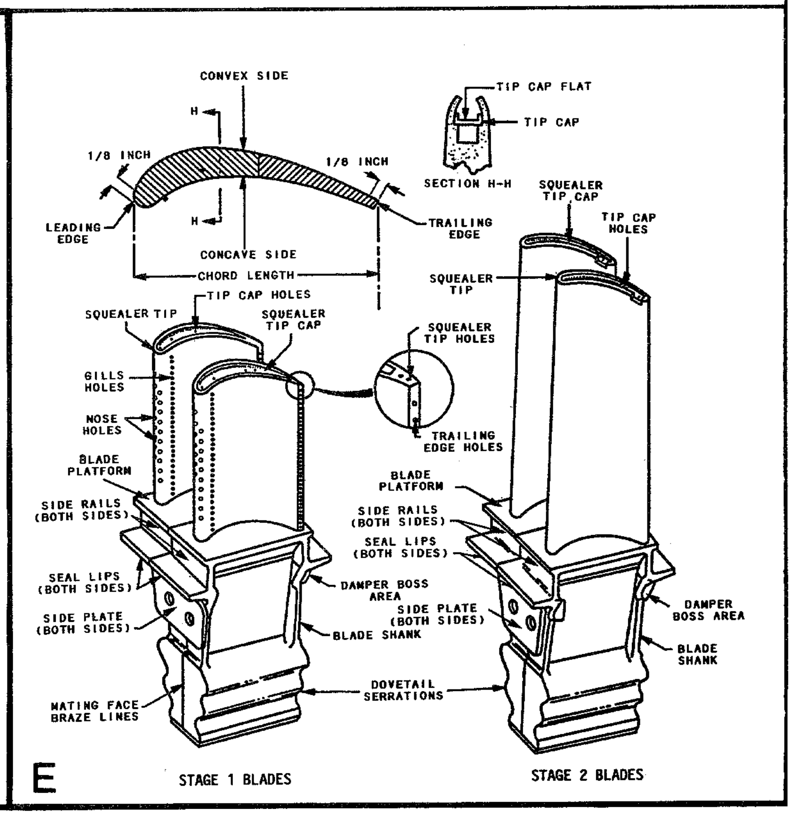
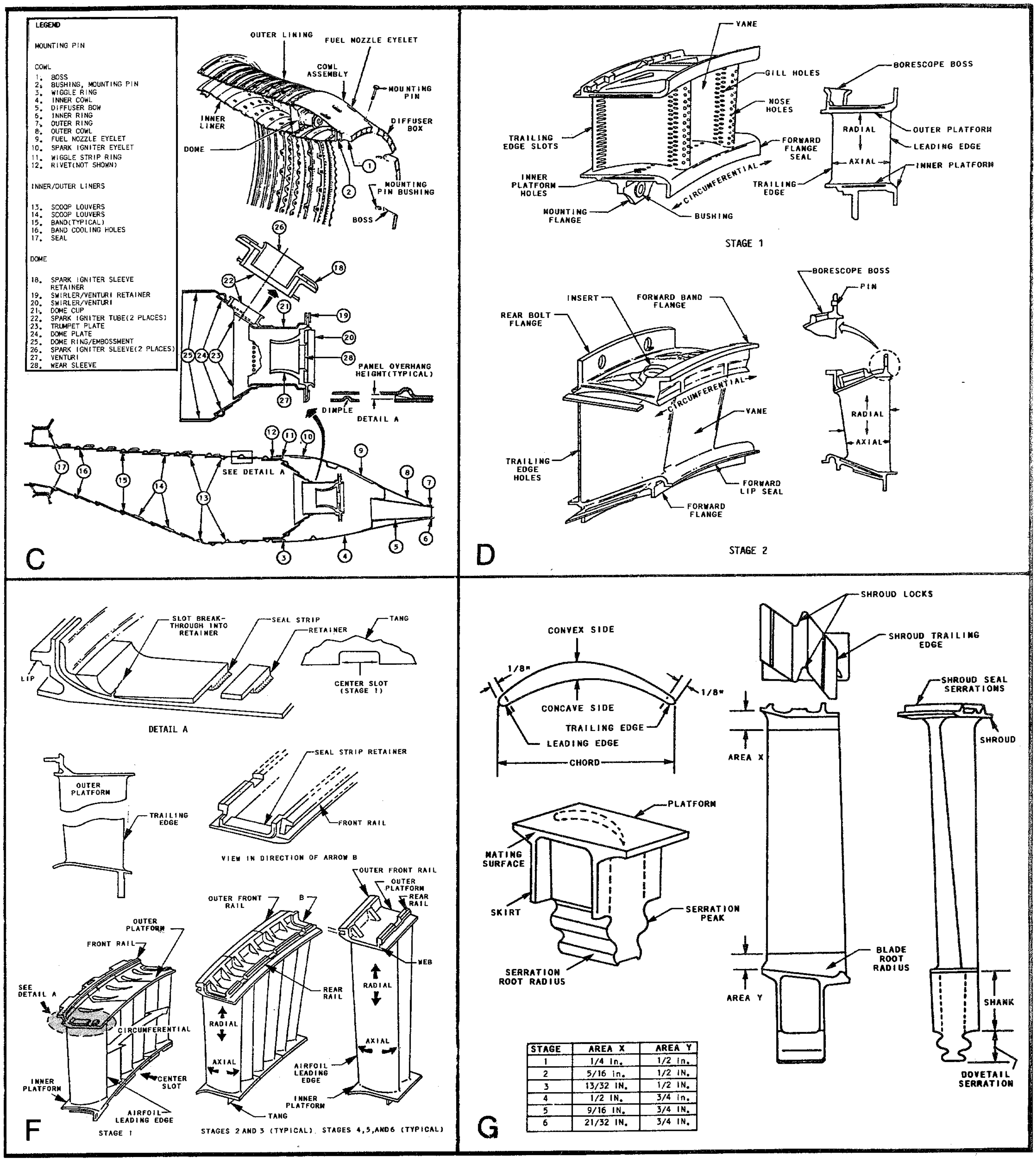


Figure 2-11a.—Engine inspection nomenclature.



STAGE	AREA X	AREA Y
1	1/4 in.	1/2 in.
2	5/16 in.	1/2 IN.
3	13/32 IN.	1/2 IN.
4	1/2 IN.	3/4 in.
5	9/16 IN.	3/4 IN.
6	21/32 IN.	3/4 IN.

Figure 2-11b.—Engine inspection nomenclature.